MAY 13 1930

Volume XXIX May, 1930 Number 5

SOIL SCIENCE

Editor-in-Chief
JACOB G. LIPMAN

Associate Editor
HERMINIE BROEDEL KITCHEN

Contents

Equipment and Procedure for Obtaining the Displaced Soil Solution. JOHN P. CONRAD, E. L. PROEBSTING, AND L. R. MCKINNON 323

Translocation of Calcium in Soils as Measured by Electrodialysis and Plant Growth. BENJAMIN D. WILSON 331

Determination of Calcium in the Presence of Iron and Aluminum. R. C. WILEY 339

A Method of Studying the Activity and Rate of Diffusion of Protozoa and Bacteria in the Soil. L. LOSINA-LOSINSKY AND P. F. MARTINOV 349

The Effect of Alfalfa and Sweet Clover Roots and Tops on Carbon Dioxide Evolution and Accumulation of Nitrates in the Soil. THOMAS L. MARTIN . 363

Effect of Cropping with Various Fertilizer, Manure, and Lime Treatments upon the Exchangeable Bases of Plot Soils. C. J. SCHOLLENBERGER AND F. R. DREIBELBIS 371

The Purdue Technique for Taking and Mounting Monolithic Soil Profile Samples. T. M. BUSHNELL 395

The Approximate Size of Soil Particles at Which the Heat of Wetting is Manifested. LAWRENCE C. KAPP 401

Book Reviews 413

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
BALTIMORE, MARYLAND, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

EDITORIAL BOARD

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.

PROF. K. ASO
Imperial University, Tokyo, Japan

PROF. C. BARTHEL
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

PROF. A. W. BLAIR
Rutgers University, New Brunswick, N. J.

DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa

PROF. DR. ALBERT DEMOLON
Ministry of Agriculture, Paris, France

DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.

DR. E. B. FRED
University of Wisconsin, Madison, Wis.

DR. J. E. GREAVES
Utah Agricultural College, Logan, Utah

DIRECTOR ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium

DR. B. L. HARTWELL
Rhode Island Experiment Station, Kingston, R. I.

DR. D. J. HISSINK
Agricultural Experiment Station, Groningen, Holland

DR. C. B. LIPMAN
University of California, Berkeley, Calif.

DR. BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.

DR. F. LÖHNIS
University of Leipsig, Germany

DR. T. L. LYON
Cornell University, Ithaca, N. Y.

DR. M. M. MCCOOL
Michigan State College, East Lansing, Mich.

DR. W. H. MACINTIRE
University of Tennessee, Knoxville, Tenn.

DR. E. A. MITSCHERLICH
University of Königsberg, Prussia

PROF. C. A. MOOERS
University of Tennessee, Knoxville, Tenn.

DR. SVEN ODÉN
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

DR. THEO. REMY
Institut für Boden- und Pflanzenbaulehre, Bonn a. Rh.

PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy

DR. E. J. RUSSELL
Rothamsted Experimental Station, Harpenden, England

DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.

DR. ALEXIUS A. J. DE'SIGMOND
Royal Hungarian Joseph University of Technical Sciences, Budapest, Hungary

DR. J. STOKLASA
Technical High School, Prague, Czechoslovakia

PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio

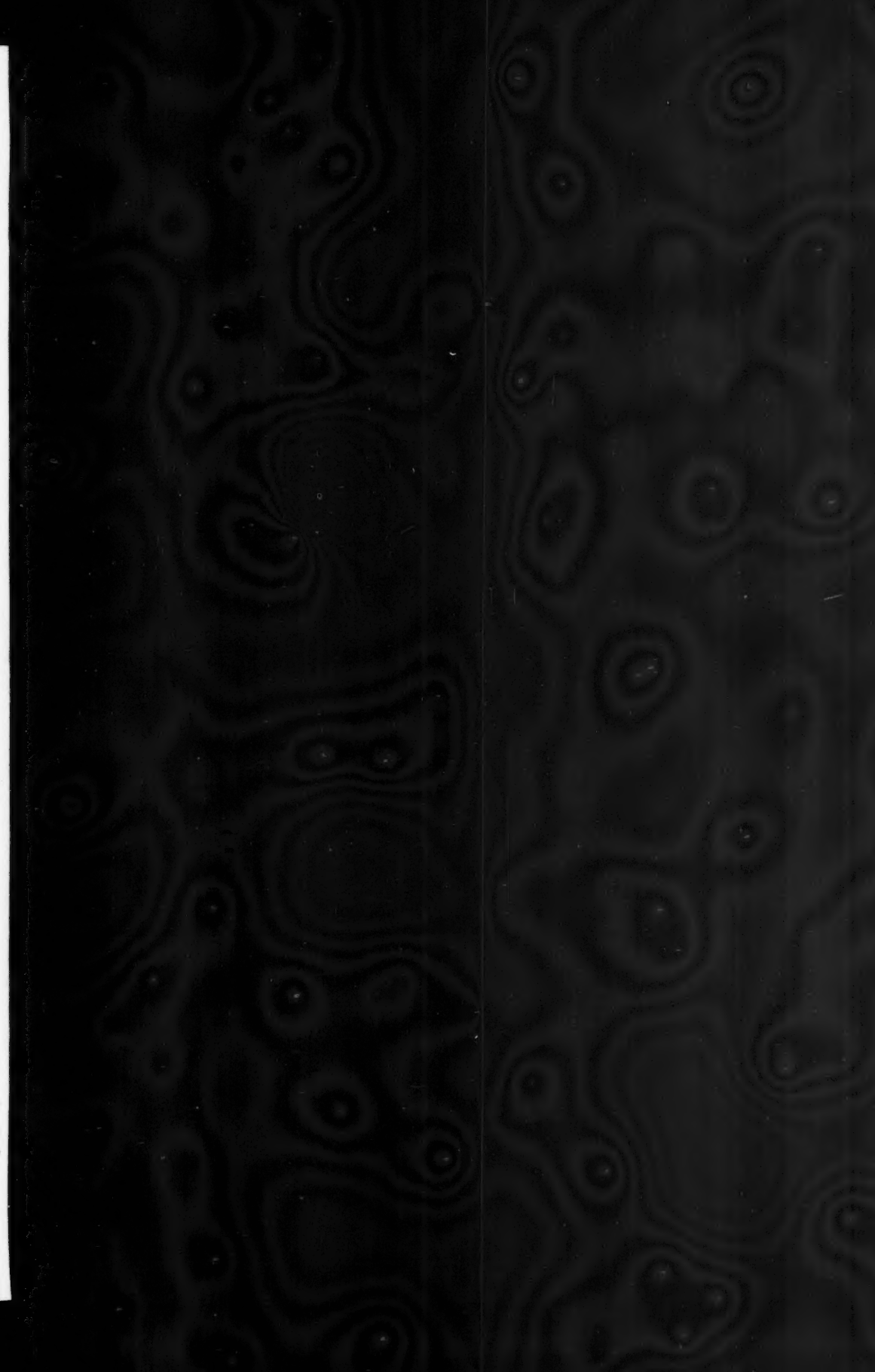
PROF. N. M. TULAIKOV
Agricultural Experiment Station, Saratov, Russia

DR. S. A. WAKSMAN
Rutgers University, New Brunswick, N. J.

DR. F. WEIS
Royal Agricultural and Veterinary College, Copenhagen, Denmark

PROF. S. WINOGRADSKY
Pasteur Institute, Paris, France

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879
Copyright, 1930, The Williams & Wilkins Company



EQUIPMENT AND PROCEDURE FOR OBTAINING THE DISPLACED SOIL SOLUTION

JOHN P. CONRAD, E. L. PROEBSTING, AND L. R. McKINNON

University of California

Received for publication October 18, 1929

The displaced soil solution from plots in the field as well as from soil in experiments under more controlled conditions was required for certain studies. Because it was felt that the method of Burd and Martin (2) gave a solution most closely approximating the soil solution surrounding the roots, the displacement method was selected. The use of this method limits the number of such field plots which can be included in a given experiment. It is dependent upon many factors, among which are the amount of solution necessary (at the concentrations found) to make the analyses desired, the percentage of moisture present in the sample, the fraction of that moisture obtained by displacement before dilution by the displacing water, and the capacity of the equipment used.

The number of aliquots and the size of each determine the amount of displaced solution necessary for the analyses desired. When gravimetric, volumetric and electrometric methods are to be used, the size of aliquots desired or necessary at the concentrations found in the field soils examined at Davis are as shown in table 1.

The amounts given in table 1 are the sizes of aliquots generally used in the determinations, though not all of those listed are run on all samples obtained. This total amount allows only a single determination for each ion analyzed. The use of colorimetric methods which have been adopted for some ions reduces the total solution required. Thus with the colorimetric methods for potassium where sodium is not determined, 20 cc. is used; for phosphate, 25 to 100 cc.; for nitrate (phenol disulfonic acid method) 5 cc., instead of the amounts given in the table.

The effect of variation in the moisture percentage of the sample is obviously an important factor in the yield of solution obtained. Furthermore, the fraction of moisture in the soil which may be obtained undiluted by the displacing water is a factor that often gives the analyst great concern. Burd (1), working with light soils, generally obtained yields of 75 per cent or more of the moisture in the soil before dilution started. Working with field soils at Davis, the writers have not been so fortunate. Water was not mixed with the soil before displacement, as in the carefully controlled experiments of Burd and Martin. This practice was adopted in order to determine the conditions in the field as nearly as possible without change.

The amount of moisture in the soil obtained in the monthly samples undoubtedly influenced the percentage yield more than did any other factor. When the soils used were relatively wet or relatively dry, the percentage yield was less than when intermediate moisture conditions obtained. With these particular soils the moisture equivalent is about 24 per cent and the wilting coefficient, computed from ratios found on similar soils by Veihmeyer and Hendrickson (4), about 11 per cent. When samples are taken soon after a rain or irrigation, before downward movement of water has ceased, at moisture contents above 24 per cent, they generally yield no solution. This is probably due to puddling when displacement is attempted. From 24 per cent down to 15 to 18 per cent moisture, the percentage yield ranges from 10 to 40 per cent with an average of 25. The yield decreases to about 10 per cent at 12 per cent moisture, and almost to zero at 10 to 11 per cent moisture. Only a few samples have been displaced at moisture contents below 12 per cent but with these

TABLE 1

Amounts of soil solutions necessary for determination of various ions

DETERMINATIONS (NOT COLORIMETRIC)	SIZE OF ALIQUOT
	cc.
Calcium, magnesium, and sulfate	100
Sodium and potassium	100
Phosphate	200
Nitrate (by DeVarda method)	100
pH (electrometrically)	5
Specific conductance	*
Chlorine, carbonate, and bicarbonate	50
Total	555

* Determined as part of displacement procedure. No solution lost.

it was very difficult to get enough solution for analysis. It was noticed that samples from one plot at one corner of the experimental area where the soil was slightly heavier (moisture equivalent of 26 per cent) were exceedingly difficult to displace at any moisture content. This soil, a Yolo loam, apparently approaches the limit of easy displacement with this equipment. It is possible, however, that soils with approximately the same moisture equivalent but belonging to another series may "displace" readily.

A battery of 8 brass tubes, similar to those used by Burd and Martin, i.e., each about 3 inches in diameter, was obtained by the division of pomology. To get enough solution for the determinations desired, it was generally necessary to use four tubes for each sample of soil. Though a number of advantages accrue from the use of more than one tube for each sample of soil, as stressed by Burd and Martin (2), the work involved is tremendous when many samples are to be analyzed. For this reason it was decided to increase the

diameter to 6 inches, thereby multiplying the cross-sectional area by 4. The increased size of the tube and especially the greater amount of soil used made it advisable to change the set-up materially without altering the principles involved.

Since a brass tube of this size would be comparatively expensive, an iron tube was tried in July, 1927. To prevent chemical reaction between the soil and the iron, the inside was coated with spar varnish. This, however, soon

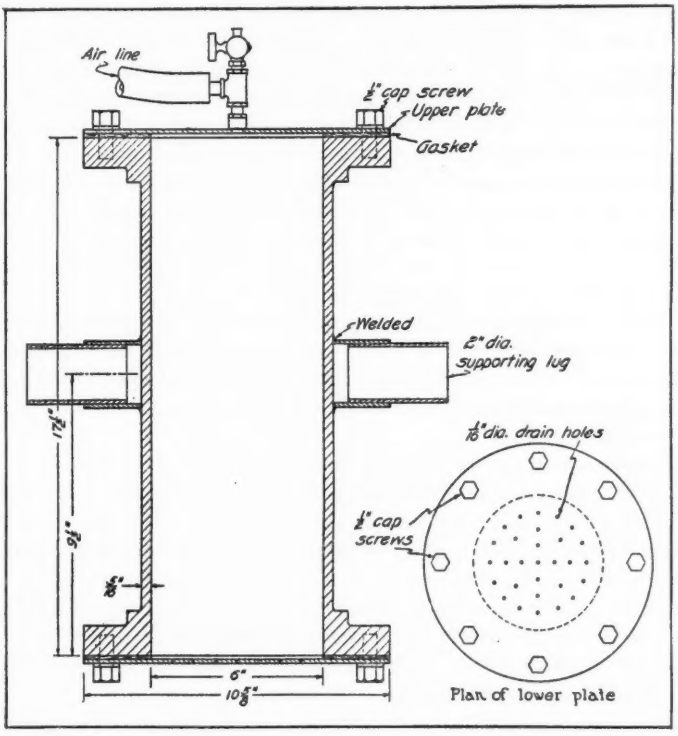


FIG. 1. DIAGRAM OF A LARGE TUBE FOR OBTAINING THE DISPLACED SOIL SOLUTION

wore off in discharging the soil. The practice of using petrolatum or cup grease on the sides of the tubes to stop channeling undoubtedly prevented chemical reaction there, but a possibility remained for reaction on the fact of the bottom plate and the sides of the filtering holes. This can be taken care of by frequent renewals of the varnish or, better, by coating the plate with a thin layer of cup grease. It might be expected that any iron going into solution would react with the phosphate. The constancy of the phosphate value would seem to indicate, however, that this is of relatively little importance.

With the 3-inch brass tubes, the former practice was to dig and shake out the soil after displacement, a procedure which involved difficulty except with light soil. It was discovered that if the bottom cap was removed the soil could be easily discharged by using the air pressure. It was considered desirable also to save this time and labor in using the larger tube.

The heavy weight of this tube and the increased amount of soil used necessitated a more or less permanent mounting for the tube. Figure 1 shows a diagram of a tube. A piece of wrought iron water pipe 6 inches in diameter and 18 inches long was threaded on each end. Standard flanges, with red lead in the joints, were screwed on tightly so that the pipe extended slightly beyond the surface of the flange. This extension was filed off flush. Sheet rubber gaskets reaching to the inner edge of the tube were provided for the flanges. Top and bottom plates of $\frac{3}{16}$-inch iron were provided with bolt holes to register with those in the flanges. A hole threaded for $\frac{3}{8}$-inch pipe in the center of the top plate provided a means of connecting a hose carrying compressed air. Many small $\frac{1}{16}$-inch holes were bored in that part of the lower plate which registered with the inside of the tube. To each side of the outside of the tube, slightly above its center, a 2-inch-pipe coupling was welded. Into each of these a nipple was later threaded to assemble the set-up (shown in plate 1) and to allow the bottom to be swung up for tightening and loosening the lower bolts. A funnel supported by a ring stand was adjusted fairly tightly beneath the holes in the bottom plate to catch the displaced solution. The loss by evaporation was reduced to a minimum by exposing as little surface as possible to air currents.

In making a displacement, slightly more than 8 kgm. of soil is taken from a single plot by the use of a soil tube, and is brought to the laboratory in a covered pail. With the displacement tube dry, greased on the sides, and the bottom covered with a 6-inch filter paper, the sample is placed in the tube in 7 to 10 increments, each one being rammed down with the tamper shown in plate 1. No attempt is made to bring the soil moisture up to optimum, the soil being displaced at the moisture percentage occurring in the field at the time of sampling. Two liters of distilled water is added above the soil, the funnel is adjusted, and a flask to catch the drippings is provided.

The labor of displacing with one large tube is reduced to slightly more than one-fourth that for the four small tubes holding the same amount of soil. The larger tube takes slightly longer to pack than one of the smaller tubes. Removing the flanges and replacing them for the larger tubes take slightly longer than for the same number of small tubes. With the set-up of the large tubes perhaps the position of the solution caught—near the floor—is a disadvantage as compared to the set-up of the smaller tubes where the solutions are caught at table height, but after many hundreds of displacements the stooping-over has not been found unduly irksome. Undoubtedly with the tubes mounted somewhat higher and with a movable platform to facilitate packing, even this might be easily overcome.

The procedure followed in making a displacement with this equipment is similar to that with the small tubes. Packing generally takes place in the afternoon with the soil at Davis, the water being allowed to stand on the soil overnight without air pressure. With lighter soils the displacement may be made at once. In the morning the pressure is gradually increased to 50 pounds to the square inch. The use of pressures up to 200 pounds to the square inch was found to be undesirable because puddling of the soil occurred, resulting in a decreased yield. Successive aliquots of about 50 cc. each are tested by electrical conductivity for the "break," i.e., when dilution causes

TABLE 2

Comparison of specific resistances of solutions from field samples displaced in large tubes and in small tubes

PLOT NUMBER	DATE	SPECIFIC RESISTANCE	
		Solution from large tubes	Solution from small tubes
		ohms	*ohms*
Pear B6	May 13	161	159
Peach B4	15	169	180
Pear B2	16	226	232
Pear B3	16	146	142
Pear B7	17	172	167
Plum B1	24	218	209
Plum B2	25	218	230
Plum B7	27	188	188
Apple B4	31	176	178
Peach B1	June 5	130	130
Peach A1	7	138	140
Peach A5	10	111	103
Pear A7	12	123	121
Cherry A4	27	111	107
Apricot A4	27	126	111
Apricot A3	28	111	130
Apple B4	July 1	153	157
Apricot B3	2	149	147

the conductance to decrease. The composite solution of the portions taken before the "break" are used for analysis.

To clean out the tube, the lower plate is removed and a bucket or can of adequate size placed beneath. By turning on the air pressure slowly the soil may be discharged without much spattering of the muddy water. It is desirable to clean the tube soon after the soil is discharged in order to prevent caking of mud on the sides. Plate 1 shows some stages in packing, displacing, and discharging.

No differences apparent at present to the writers have been encountered between the solution obtained from one of the 6-inch tubes and that from a

number of 3-inch tubes. When an insufficient amount of solution was obtained to make all of the analyses desired, a "repeat" was run the following day on an additional sample from the field plot concerned. Most of these were displaced in the small tubes but some were displaced in the large tube. The sample for the large tube was a composite of about 16 to 20 samples taken from a single field plot, whereas the sample for the "repeat" in the small tubes was usually a composite of 4 to 8 field samples. The "repeats" with the large tubes, consequently, are closer in composition to the initial sample than are those with the small tubes. No analyses in common were run on both the initial displacements and the "repeats," but conductivity measurements were made on each. A few selected at random are given in table 2.

Analytical results for the composition of the displaced solutions obtained from this soil have been reported on elsewhere (3).

REFERENCES

(1) BURD, J. S. 1925 Relation of biological processes to cation concentrations in soils. *Soil Sci.* 20: 269–283.

(2) BURD, J. S., AND MARTIN, J. C. 1923 Water displacement of soil and the soil solution. *Jour. Agr. Sci.* 13: 265–295.

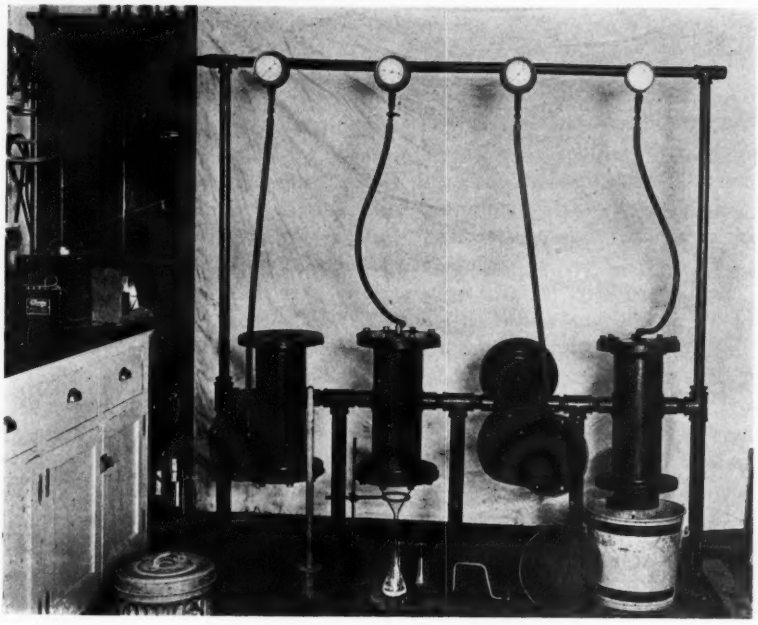
(3) PROEBSTING, E. L. 1929 Changes in the nitrate and sulfate content of the soil solution under orchard conditions. *Hilgardia* 4: 67–76.

(4) VEIHMEYER, F. J., AND HENDRICKSON, A. H. 1928 Soil moisture at permanent wilting of plants. *Plant Physiol.* 3: 355–357.

PLATE 1

A BATTERY OF LARGE SOIL DISPLACEMENT TUBES

The first tube, at the left, is ready to be packed for displacement. The tamper is shown beside the tube. The second is being displaced at 20 pounds pressure. The third has the bottom swung up for removing the lower plate. The fourth shows the charge being expelled with air pressure.



TRANSLOCATION OF CALCIUM IN SOILS AS MEASURED BY ELECTRODIALYSIS AND PLANT GROWTH

BENJAMIN D. WILSON

Cornell University

Received for publication October 10, 1929

In a previous study (5) of the translocation of calcium through a soil no fixation of the element was found. The experiment consisted in treating a heavy soil of pH 5.7 with varying quantities of lime and leaching the soil, which was held in pots, with distilled water at irregular intervals. At the end of one year different layers of the soil were analyzed for their total calcium content. If the soil adsorbed calcium from the drainage water as it percolated through the soil, the quantity fixed was insufficient to be measured by chemical analysis when total calcium was used as a measure.

Since the publication of the article referred to, several contributions relating to this subject have appeared. Some of them are reviewed by Nelson (4) in a report on the downward movement of calcium resulting from an application of lime to pasture land. He found that the treatment exerted its influence, in large measure, at the zone of application but that the reaction of the soil to a depth of 9 inches indicated a tendency for a gradual penetration of calcium through the soil. The experiment was conducted for a period of 6 years. Whether the change in the reaction of the soil resulted from a mechanical movement of the material applied or from the adsorption of calcium by the soil is not apparent.

In the present investigation an attempt was made to determine the transition of calcium in soil by means of electrodialysis and plant growth. It occurred to the writer that a slight movement of calcium that would not be shown by an analysis of soil for total calcium might be detected from determinations of exchangeable calcium and crop response. Surface layers of soil were treated with lime and after the soil was leached with distilled water, or subjected to natural weathering, the calcium content of the lower layers of soil was ascertained. The investigation consisted of field and greenhouse experiments, cylinders being used as soil containers in the field and pots in the greenhouse.

SOILS OF THE INVESTIGATION

Soils of three different series were employed in the investigation, a Dutchess silt loam, a Volusia silt loam, and a Lordstown stony silt loam. Each of these soils originated from the weathering of glacial till. The Dutchess silt loam soil, which is derived from shale and quartzite, is classified as a soil of medium

fertility. Its reaction was pH 4.6. The other two soils are derived from shale and sandstone and are very infertile. The hydrogen-ion concentration of the Lordstown stony loam soil was 4.7 and that of the Volusia silt loam soil was 4.9.

At the conclusion of the experiments samples of the soils were air dried and prepared for analysis. They were passed through a 1-mm. sieve, stones larger than 1 mm. being discarded.

CYLINDER EXPERIMENT

Cylinders previously buried with their upper rims slightly above the surface of the ground were filled with the soil of the Dutchess series or that of the Volusia series. The cylinders, which were 2 feet wide and 3 feet deep, were open at the bottom and rested on native subsoil. The soils were placed in them in three layers, each of which comprised 1 foot of soil. When the soils

TABLE 1

Treatment of cylinder soils

SOIL	CYLINDER NUMBER	TREATMENT, POUNDS PER ACRE				SYMBOL OF TREATMENT*
		Limestone	Nitrate of soda	Acid phosphate	Muriate of potash	
Dutchess silt loam	31	...	...	...	...	O
	32	...	3,027	4,356	1,213	F
	30	27,176	...	...	...	L
	29	27,176	3,027	4,356	1,213	L F
Volusia silt loam	52	...	...	...	...	O
	53	...	3,027	4,356	1,213	F
	51	35,854	...	...	...	L
	50	35,854	3,027	4,356	1,213	L F

* F = fertilizer; L = limestone.

were collected for the experiment they were sampled to a depth of 3 feet, each foot being maintained as a separate lot of soil. The samples were brought to Ithaca, New York, and placed in the cylinders in the same relative position as the soil had existed in nature, the soil from the third-foot depth being placed in the cylinders first, the soil from the second-foot depth next in order, and the soil from the surface foot in the upper part of the cylinders. The soils were subjected to natural weather conditions.

After being fertilized in a number of ways, the soils were planted to a 4-year rotation of fodder corn, timothy, barley, and clover. Only the treatments shown in table 1 will be considered here. It may be seen that the soil of one cylinder in each series remained untreated whereas the soil of the others received either limestone or fertilizers or both. Limestone was applied at the

beginning of the experiment in sufficient quantity to satisfy the lime requirement of each soil to a depth of 1 foot as determined by means of the Veitch method. The limestone that was applied was soft in character and 65 per cent of it passed through a 100-mesh screen. It contained approximately 98 per cent calcium carbonate. Additional applications were made to the limestone-treated soils when they were seeded to clover. Fertilizers were added each year. Nitrogen was not applied, however, in those years in which clover appeared in the rotation.

After 15 years the experiment was discontinued and the three layers of soil were removed separately from each of the cylinders. A separation of this kind was possible because of the distinct features of the soil comprising the different layers. Representative samples of the second- and third-foot layers of soil

TABLE 2

Carbonate in the first foot and exchangeable calcium in the second and third feet of soil from cylinder experiment, conducted for 15 years

SOIL	TREATMENT OF CYLINDER	CARBONATE* IN FIRST FOOT OF SOIL	MILLIGRAM EQUIVALENTS IN 100 GM. OF AIR-DRY SOIL	
			Exchangeable Ca in second foot of soil	Exchangeable Ca in third foot of soil
Dutchess silt loam	O	0.98	1.55	3.57
	F	1.29	1.37	3.62
	L	8.37	2.13	3.39
	LF	8.24	1.93	3.67
Volusia silt loam	O	0.49	1.55	4.47
	F	0.57	1.66	4.42
	L	17.69	1.89	4.26
	LF	17.98	2.32	4.30

* Carbonate, expressed in milligram equivalents of Ca to 100 gm. of air-dry soil.

were analyzed for exchangeable calcium to ascertain whether calcium had accumulated in them to a measurable degree during the course of the experiment. Because of the accuracy with which exchangeable calcium may be determined, it, rather than total calcium, was used as a measure of the fixation of calcium.

Exchangeable calcium was determined by electrodialysis according to the method of Bradfield (1). The apparatus as employed is referred to in previous publications from this laboratory (6). In the present work 20 gm. of soil were electrodialyzed for 8 hours under the influence of a direct current of 110 volts with suitable resistance in the circuit. However, the resistance within the cell was such that the amperage was never more than 50 milliamperes and usually considerably less. The diffusate from each of the soils was analyzed for calcium gravimetrically by means of the ammonium-oxalate method.

In table 2 are recorded the quantities of exchangeable calcium which were found in the second and in the third layers of soil. The table also shows the carbonate content of the treated layer, or the first foot of soil, at the conclusion of the experiment. The values shown are expressed in calcium equivalents. A comparison of the quantities of exchangeable calcium in the second layers of soil with respect to both soil series, suggests that calcium was adsorbed by each of the soils when its surface layer was treated with limestone. The fixation of calcium may have been more significant than is revealed by these data since the plants grown on the soils treated with limestone made a better

TABLE 3

Growth of sweet clover in the lower layers of soil and their content of exchangeable calcium after the crop was removed

Calcium applied as precipitated $CaCO_3$

NUMBER OF POT	LIME APPLIED TO UPPER LAYER OF SOIL (CaO TO THE ACRE)	SWEET CLOVER, DRY MATTER			EXCHANGEABLE CALCIUM IN SOIL AFTER GROWTH OF CROP†
		First cutting (growth period 136 days)	Second cutting (growth period 61 days)	Total weight of crop	
	pounds	*gm.*	*gm.*	*gm.*	
1	None	1.6	0.5	2.1	0.96
2	None	1.8	1.0	1.8	0.93
3	None	1.9	0.9	2.8	1.07
4	None	0.4	1.1	1.5	1.27
5	3,000	5.0	1.7	6.7	0.95
6	3,000	6.5	2.7	9.2	1.53
7	3,000	8.0	3.5	11.5	0.95
8	3,000	8.8	1.9	10.7	1.72
9*	18,000	...	...	...	...
10	18,000	8.0	4.7	12.7	1.68
11	18,000	11.9	3.2	15.1	2.39
12	18,000	12.4	3.2	15.6	1.43

* Omitted because of the mechanical movement of carbonate.

† Milligram equivalents in 100 gm. of air-dry soil.

growth than did those grown on the unlimed soil. It is possible that more calcium was removed by the plants from the second layers of soil when limestone was applied to the upper layers than when it was not applied. Analyses of the second layers of soil for carbonate showed them to contain negligible quantities of this constituent. This would indicate that the differences in the content of exchangeable calcium found in the second layers of soil could not be ascribed to a mechanical movement of limestone.

Calcium is not shown to have been adsorbed by the soil of the third foot. If a transition of calcium occurred in either of the soils of the experiment fixation did not occur beyond the second foot of soil. In any event the amount

adsorbed below the treated layer, resulting from relatively large applications of limestone, was extremely small. The results of the present experiment are in accord with the findings of Conner, Walker, and Plice (2). From determinations of soil reactions and exchangeable calcium, they concluded that very little calcium was fixed in subsoil when heavy applications of lime were incorporated in the surface horizon. This was true in spite of a considerable loss of the applied calcium from the surface soil of limed plats. The results of Crowther (3) appear to be somewhat more pronounced than those just cited. He found that lime applied to soil at Rothamsted and at Woburn changed the reaction of each to a depth of 36 inches during a period of about 20 years. It would appear from the results of the articles referred to and from those of the present experiment that calcium is adsorbed by soil from drainage water but that the process of fixation is exceedingly slow.

POT EXPERIMENT

Twelve glazed earthen pots 10 inches high and 9.5 inches in inside diameter were filled with Lordstown stony silt loam soil from which the larger stones had been removed. The soil was placed in the pots in two layers with a circular piece of wire netting between them. The bottom layer consisted of 10 kgm. of soil. The lime with which the soil was treated was mixed with 2 kgm. of soil, which comprised the top layer. Four of the pots remained untreated; an equal number of pots received an application of lime either at the rate of 3,000 pounds or 18,000 pounds of calcium oxide to the acre. Lime was added in the form of precipitated calcium carbonate. The treatment of each pot is recorded in table 3.

The pots were leached in the greenhouse with distilled water at intervals for 15 months. Water was applied irregularly at the rate of 38 inches of rainfall per annum but an equal quantity was applied each month. Drainage was provided by means of an opening one-half inch in diameter in the center of each pot. To prevent the soil from washing through the aperture, a small flower-pot was inverted over it before the soil was placed in the pot.

After leaching was discontinued the top layer of soil was removed from each pot as soon as the soil was sufficiently dry to be handled. This was accomplished easily by removing the soil to the depth of the wire netting. A thin layer of soil was removed just below the netting to insure the removal of all of the soil that was originally a part of the upper layer. The soil remaining in the pots was then inoculated with a suitable bacterial culture and planted to sweet clover. The pots were held at constant moisture content.

As has been stated, the soil of the experiment is very infertile. It requires the addition of lime in some form for the production of legumes. Since one of the objects of the experiment was to measure the translocation of calcium from the upper layer to the lower layer of soil by means of crop response, sweet clover was selected because of its sensitivity to soil reaction and its response to applications of lime. The results of the test are to be seen in table 3.

Sweet clover grew considerably better on the soils the upper layers of which had been treated with calcium carbonate, and best on the soils the upper layers of which had received the larger application of this material. The clover was grown for 197 days. The data indicate that, as the calcium moved downward from the treated layers of soil, a part of it was fixed in the lower layers. After the second growth of sweet clover was cut, the soil was removed from the pots as a solid cylindrical mass. To avoid introducing into the sample any calcium carbonate that might have moved downward mechanically through the soil or between the soil and the pot, only the central part of it was sampled in preparation for the analysis of carbonate and exchangeable calcium.

Inappreciable quantities of carbonate were found in the second layers of soil, with the exception of that of pot 12. In this instance it was evident from the quantity found that a mechanical movement of calcium carbonate had occurred. Its movement was also reflected in the growth of sweet clover which was decidedly better on the soil of pot 12 than on the soil of any of the other pots.

The quantity of exchangeable calcium found in each of the second layers of soil, after they had been cropped to sweet clover, is recorded in the last column of table 3. There is some doubt whether the smaller application of calcium carbonate to the upper layer of soil increased the exchangeable calcium in the soil of the adjacent layer as measured by the method employed. Nevertheless the tendency appears to be in that direction. The larger application of calcium carbonate to the upper layer of soil, however, appears definitely to have increased the exchangeable calcium in the lower layer. Thus a relationship seems to exist between the growth of sweet clover on the soil of the experiment and its content of exchangeable calcium. As in the case of the cylinder experiment, the plants on the limed soil made a greater growth than those on the unlimed soil. This would tend to minimize the quantity of exchangeable calcium shown to be fixed in the lower layers of soil.

SUMMARY

Cylinders and pots were filled with soil arranged in layers. In each case the surface layer of soil was treated with limestone or precipitated calcium carbonate. Soils of three different series, all acid in reaction, were employed in the experiments.

The soils of the cylinders were exposed to natural weathering for 15 years, during which time they were cropped to a rotation of fodder corn, timothy, barley, and clover. The soil of the pots was leached with distilled water for 15 months after which the upper layer of soil was removed and the lower layer planted to sweet clover. The experiment with the potted soil was conducted in the greenhouse.

At the end of the experiments the quantity of calcium that was fixed in layers of soil below lime-treated layers was ascertained by analyzing the soil

for exchangeable calcium by means of electrodialysis. The growth of sweet clover was also used as a measure of the translocation of calcium from lime-treated to untreated layers of soil.

Under the conditions of the experiments, calcium was found to be fixed in each of the three soils below layers of soil that had been treated with lime. With one exception, no mechanical movement of the limestone or of the precipitated calcium carbonate was indicated from analysis of the soils for carbonate.

It is evident from the results presented that the soils of the investigation adsorbed exceedingly small quantities of calcium from the drainage water as it passed through them. Nevertheless the quantity so fixed was of sufficient magnitude, during a comparatively short period, to influence materially the growth of sweet clover.

REFERENCES

(1) BRADFIELD, R. 1927 A simplified cell for determining the electrodialyzable base content of soils and permutits. *Jour. Amer. Soc. Agron.* 19: 1015–1020.

(2) CONNER, S. D., WALKER, G. P., AND PLICE, M. J. 1928 Soil acidity and base exchange studies on two very acid soils. *Proc. and Papers. First Internatl. Cong. Soil Sci.* 2: 136–143.

(3) CROWTHER, E. M. 1925 Studies on soil reaction: V. The depth-distribution of reaction and flocculation in continuously manured soils. *Jour. Agr. Sci.* 15: 232–236.

(4) NELSON, P. R. 1929 Lime penetration resulting from surface application to pasture land. *Soil Sci.* 27: 143–146.

(5) WILSON, B. D. 1918 The translocation of calcium in a soil. *N. Y. (Cornell) Agr. Exp. Sta. Mem.* 17: 299–324.

(6) WILSON, B. D. 1930 Exchangeable calcium and potassium in soils as affected by cropping and fertilization. *Soil Sci.* 19: 91–100.

DETERMINATION OF CALCIUM IN THE PRESENCE OF IRON AND ALUMINUM[1]

R. C. WILEY

University of Maryland

Received for publication October 15, 1929

The purpose of the following experiments was to find a rapid and accurate means of separating the alkaline earth ions from the hydroxides of iron and aluminum. The investigation was confined to the separation of the calcium ion from these hydroxides, when they are precipitated in its presence.

In this paper the standpoint of the analyst is taken. Any loss or adsorption from solution must be of sufficient magnitude to be detected by careful analytical procedure, or it will not be deemed adsorption or recognized as such.

Silica, iron, aluminum, magnesium, calcium, and carbon dioxide are present in many naturally occurring rocks. In the analysis of such material, after the silica is removed, the hydroxides of iron and aluminum are precipitated and thus separated from the alkaline earth metals. Does any considerable portion of the alkaline earth metals, for example calcium, remain with the trivalent hydroxides when the separation is made?

Mahin (4) states that at the moment of flocculation a substance having a large surface may show the effect of adsorption to a marked degree and soluble salts be taken from solution, also that the hydroxides of iron, aluminum, and chromium retain dissolved salts of bases with great tenacity and are extremely difficult to purify by washing.

Hendel (3) believes that occlusion, that is, the enclosing of foreign matter by a crystal, occurs in all precipitations. His idea is that the impurity may be either mother liquor, which is mechanically enclosed while the crystal is forming, or it may be matter which forms a solid solution with the crystal. He notes that precipitates that are curdy or gelatinous must be considered as made up of crystals of ultramicroscopic size, and since such crystals are formed rapidly they are likely to occlude much foreign matter.

Hendel also finds that the precipitates of the mixed hydroxides of iron, aluminum, manganese, titanium, and phosphorus formed by a slight excess of 15-molar ammonium hydroxide are contaminated with calcium and magnesium

[1] Extracts from a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy, May, 1927, at the American University. The writer wishes to acknowledge the valuable suggestions for the preparation of this article, given by Dr. Oswald Schreiner, U. S. Department of Agriculture, and by Dr. L. B. Broughton, head, chemistry department, University of Maryland.

salts. He recommends double precipitation. If only the hydroxides of iron and aluminum were present, would there still be contamination?

Fales (2) states that in certain cases of coprecipitation recourse is had to the expedient of dissolving the contaminated precipitate and reprecipitating and that this procedure, which is known as double precipitation, is invariably followed in rock analysis where most of the salts encountered belong to members of the aluminum and iron or the alkaline earth groups.

George McPhail Smith (6) thought it possible that ferric hydroxide might form a more or less insoluble compound with the alkaline earth metals.

Dahr (1) found that ferric, aluminum, and chromium hydroxides adsorb the following positive ions: zinc, copper, nickel, cadmium, and calcium.

Talbot (7) ascribes the precipitation of calcium, which appears with the hydroxides of iron and aluminum, to the carbon dioxide of the air. Where the precipitate is small the reprecipitation may be omitted, according to this author.

Scheringa (5) doubts the correctness of the current belief that metal hydroxides adsorb salts.

From the foregoing references it would seem that there is a rather general opinion that calcium is taken from solution when the hydroxides of iron and aluminum are precipitated in its presence. There seems to be some difference of opinion, however. If calcium is taken from solution, how much would a given quantity of ferric hydroxide be expected to carry down when all ordinary precautions are taken to prevent such loss, coprecipitation, or adsorption? It would seem that the hydroxides of iron and aluminum are prone to remove solids from solution. How can this tendency be overcome? How may they be removed without resorting to double precipitation and without impairing the accuracy of the subsequent determination of calcium? If a decigram of iron in the form of hydroxide carries down a given amount of calcium, would twice that much iron carry down double the amount of calcium? Would a given amount of iron carry down more calcium from a concentrated or dilute solution?

Although several authorities claim that calcium is lost from solution when the hydroxides of iron and aluminum are precipitated in its presence, no one so far as the writer has been able to find, has measured the extent of loss. It would seem reasonable, in view of what has been published about adsorption, to assume that gelatinous precipitates such as ferric and aluminum hydroxides should adsorb the calcium ion. It should be emphasized at this point, however, that the object of these experiments is to increase the accuracy of the analysis of materials containing calcium, iron, and aluminum rather than to make a study of adsorption.

SOLUTIONS USED

The solutions used were an accurately standardized tenth-normal solution of potassium permanganate and accurately standardized tenth-molar solutions of ferric nitrate, aluminum nitrate, and calcium nitrate.

The potassium permanganate was standardized against pure sodium oxalate. The calcium nitrate solution was made by weighing out the required amount of iceland spar, dissolving it in nitric acid, evaporating the solution to dryness, and then making the residue up to volume. To check further the accuracy of both the potassium permanganate and the calcium nitrate solutions, the calcium from 25 cc. of the calcium nitrate solution was precipitated as the oxalate, dissolved, and titrated against the potassium permanganate in the usual way. This was repeated several times with close agreement. The quantity of iron and aluminum in the respective solutions was determined gravimetrically by precipitating them as their hydroxides, washing, igniting, and weighing them as the oxides in the usual way. No calcium was present in either.

GENERAL PLAN OF EXPERIMENTAL PROCEDURE

The general plan of procedure was to pipette carefully the required amount of the tenth-molar calcium nitrate solution into a 250-cc. volumetric flask. This was followed by the addition of the required amount of the trivalent metal solution. A sufficient quantity of distilled water was added to equalize the volume in all the flasks. The distilled water was free of carbon dioxide, since it was boiled and since a solution of calcium hydroxide gave no precipitate with it. The trivalent metal was then precipitated with carbon dioxide-free ammonium hydroxide. The solutions were then boiled for a long or short period, according to the conditions of the experiment, and made up to 250 cc. An aliquot was then filtered, and the calcium determined by the permanganate method. If the quantity of calcium found in the aliquot, after the precipitation of the trivalent hydroxide, corresponded to the calculated quantity, then evidently no calcium had been lost.

Experiment 1

In this experiment the ferric hydroxide was precipitated according to the procedure described. The solutions were then boiled practically free of ammonia, or rather until the vapor from the flasks had no effect upon red litmus paper. The flasks were then trapped to prevent entrance of carbon dioxide, cooled to about 50°, and 3 cc. of 3 *N* ammonium hydroxide was added. Table 1 records the results found.

It will be seen that under these conditions some calcium is lost from solution, for it is evident from the quantity lost from the aliquots that the discrepancy is too great to be accounted for on any grounds except precipitation or adsorption. Since the amount of ammonium hydroxide present was not sufficient to cause precipitation of calcium hydroxide it would appear to be a case of adsorption. The quantity of calcium lost from solution appears to be dependent upon the quantity of iron present.

Experiment 2

Since in experiment 1 a small excess of ammonium hydroxide was added, it was decided to determine whether any calcium would be lost from a solution in which all the ammonia had been boiled off after the ferric hydroxide had

TABLE 1

Effect of excess of 3 cc. of 3 N NH_4OH upon calcium in solution in presence of ferric hydroxide

(Total calcium present initially, 0.2035 gm.)

FLASK NUMBER	IRON PRESENT	TOTAL CALCIUM LOST FROM SOLUTION*	CALCIUM IN ALIQUOT	CALCIUM LOST FROM ALIQUOT
	gm.	*gm.*	*gm.*	*gm.*
1	0.0558	0.0020	0.0407	0.00080
2	0.1116	0.0065	0.0407	0.00120
3	0.1675	0.0075	0.0407	0.00150
4	0.2233	0.0080	0.0407	0.00180
5	0.2792	0.0100	0.0407	0.00200
6	0.3350	0.0140	0.0407	0.00280
7	0.3908	0.0185	0.0407	0.00370
8	0.4467	0.0195	0.0407	0.00390
9	0.5065	0.0225	0.0407	0.00450

* Calculated from aliquot.

TABLE 2

Loss of calcium from solution when the quantity of calcium is constant (total present, 0.2035 gm.; in aliquot, 0.0203 gm.), the quantity of ferric hydroxide is varied, and all ammonium hydroxide is boiled off

FLASK NUMBER	IRON PRESENT	TOTAL* CALCIUM LOST	CALCIUM LOST FROM ALIQUOT
	gm.	*gm.*	*gm.*
1	0.0558	−0.0005	−0.00005
2	0.1116	−0.0015	−0.00015
3	0.1675	−0.0015	−0.00015
4	0.2233	−0.0005	−0.00005
5	0.2792	−0.0015	−0.00015
6	0.3350	−0.0005	−0.00005
7	0.3908	−0.0015	−0.00015
8	0.4467	−0.0005	−0.00005
9	0.5065	−0.0019	−0.00019

* Calculated from aliquot.

been precipitated, a procedure which is generally recommended in quantitative analysis.

It is quite evident from this experiment, in which so far as possible all sources of analytical error were kept constant, that any loss of calcium from solution was of a negative character. It is true that theoretically the solution should become somewhat more concentrated, because of the volume occupied by the ferric hydroxide, but it is doubtful whether this small increase in

concentration of the calcium in solution could be detected. It can be said that no loss or gain in concentration of the calcium in solution could be detected in this experiment.

Experiment 3

Since in experiment 2 it was found that the precipitation of ferric hydroxide had no appreciable effect upon the concentration of the calcium ion, it was decided to determine whether the precipitation of aluminum hydroxide under the same conditions would effect any alteration.

TABLE 3

Quantity of calcium lost from solution when aluminum hydroxide is precipitated in the presence of calcium salts and the excess of ammonia is boiled off

FLASK NUMBER	ALUMINUM PRESENT	TOTAL CALCIUM PRESENT	TOTAL* CALCIUM LOST	CALCIUM IN ALIQUOT	CALCIUM LOST FROM ALIQUOT
	gm.	*gm.*	*gm.*	*gm.*	*gm.*
1	0.0271	0.3600	0.0050	0.0144	0.00020
2	0.0542	0.3200	0.0025	0.0128	0.00010
3	0.0813	0.2800	0.0000	0.0112	0.00000
4	0.1084	0.2400	0.0000	0.0240	0.00000
5	0.1355	0.2000	0.0020	0.0200	0.00020
6	0.1626	0.1600	0.0010	0.0160	0.00010
7	0.1897	0.1200	0.0040	0.0240	0.00090
8	0.2168	0.0800	0.0010	0.0160	0.00020
9	0.2439	0.0400	0.0005	0.0160	0.00010

* Calculated from aliquot.

TABLE 4

Amount of calcium lost from solution when ferric and aluminum hydroxides are precipitated in the presence of calcium salt and the excess of ammonia is boiled off

FLASK NUMBER	ALUMINUM PRESENT	IRON PRESENT	TOTAL CALCIUM PRESENT	TOTAL* CALCIUM LOST	CALCIUM IN ALIQUOT	CALCIUM LOST FROM ALIQUOT
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.0135	0.0279	0.3600	−0.0050	0.0144	−0.00020
2	0.0271	0.0558	0.3200	0.0000	0.0128	0.00000
3	0.0406	0.0837	0.2800	−0.0075	0.0112	−0.00030
4	0.0542	0.1116	0.2400	−0.0020	0.0240	−0.00020
5	0.0677	0.1386	0.2000	−0.0020	0.0200	−0.00020
6	0.0813	0.1675	0.1600	−0.0020	0.0160	−0.00020
7	0.0948	0.1954	0.1200	−0.0020	0.0240	−0.00040
8	0.1084	0.2233	0.0800	0.0000	0.0160	0.00000
9	0.1219	0.2532	0.0400	−0.0005	0.0160	−0.00020

* Calculated from aliquot.

In this experiment the loss of calcium from solution, except in the case of no. 7, is well within the limits of analytical error. It is to be noted that under these conditions no carbonates and no excess of ammonium hydroxide were present.

Experiment 4

Neither ferric nor aluminum hydroxide alone altered the concentration of the calcium solution when precipitated. Consequently it was decided to precipitate both hydroxides in the presence of calcium from a solution of aluminum and ferric nitrate. Table 4 shows the results obtained.

TABLE 5

Effect of saturating solutions containing precipitated ferric and aluminum hydroxides and calcium salts with carbon dioxide

FLASK NUMBER	IRON PRESENT	TOTAL CALCIUM PRESENT	TOTAL* CALCIUM LOST	CALCIUM IN ALIQUOT	CALCIUM LOST FROM ALIQUOT
	Precipitated ferric hydroxide				
	gm.	gm.	gm.	gm.	gm.
1	0.0558	0.3234	−0.0005	0.0129	−0.00002
2	0.1116	0.2884	0.0090	0.0115	0.00037
3	0.1675	0.2522	−0.0075	0.0101	−0.00031
4	0.2233	0.2163	−0.0037	0.0216	−0.00037
5	0.2792	0.1802	−0.0008	0.0180	−0.00008
6	0.3350	0.1442	0.0006	0.0144	0.00012
7	0.3908	0.1081	0.0008	0.0216	0.00017
8	0.4467	0.0721	−0.0009	0.0144	−0.00018
9	0.5068	0.0360	0.00005	0.0144	0.00002
	Precipitated aluminum hydroxide				
	ALUMINUM PRESENT				
10	0.0271	0.3600	0.0050	0.1460	0.00010
11	0.0542	0.3200	−0.0075	0.0130	−0.00030
12	0.0813	0.2800	−0.0150	0.0109	−0.00040
13	0.1084	0.2400	−0.0030	0.0240	−0.00030
14	0.1355	0.2000	−0.0030	0.0202	−0.00030
15	0.1626	0.1600	−0.0020	0.0162	−0.00020
16	0.1897	0.1200	−0.0025	0.0244	−0.00050
17	0.2168	0.0800	0.0030	0.0162	0.00060
18	0.2439	0.0400	0.0022	0.0162	0.00020

* Calculated from aliquot.

It is clear from the results in table 4 that absolutely no calcium was taken from solution by the combined hydroxides of iron and aluminum. The apparent increase of calcium in solution obtained is too small to be taken into consideration since it is well within the analytical error.

Experiment 5—Effect of Carbon Dioxide

In experiments 2, 3, and 4 the boiling off of the ammonium hydroxide prevented loss of calcium from solution. It was decided to precipitate ferric and aluminum hydroxide in the usual way with a small excess of ammonia,

boil sufficiently to flocculate the precipitate, and cool in the presence of a stream of carbon dioxide. Table 5 gives results when a stream of carbon dioxide was passed through each flask for about seven minutes.

In this experiment no calcium was lost from solution as a result of the effect of cooling with a stream of carbon dioxide. The stream of carbon dioxide was started through each flask when a very small quantity of ammonia was still present. Some calcium carbonate precipitates, no doubt, and is later converted into the soluble calcium acid carbonate, which apparently was stable enough to remain in solution until the determination of calcium was made.

GENERAL DISCUSSION

From the results given in the tables it will be seen that in one experiment only (no. 1) was calcium lost from solution. In this case there was a moderate excess of ammonium hydroxide present.

In the experiments in which all the ammonium hydroxide was boiled off after the precipitation of the trivalent hydroxides no calcium was lost from the solution.

It would seem that decreasing the amount of ammonium hydroxide present in the solution, whether by boiling or by neutralizing with carbon dioxide, prevents loss of calcium from solution. If only a small amount of carbon dioxide is added, calcium carbonate will be precipitated and filtered off with the trivalent hydroxides and thus cause low results in the calcium determination. When the solution is saturated, however, no loss of calcium occurs. Doubtless the calcium carbonate first formed is converted to soluble calcium acid carbonate.

The results obtained in these experiments show that it is possible to make accurate calcium determinations without the double precipitation of the hydroxides of iron and aluminum. In some cases where such double precipitation is recommended, precautions are given which, if fully carried out, will render such double precipitation unnecessary. This is true when the solution is freed from carbonates before their precipitation and from ammonium hydroxide after their precipitation.

It is thought possible in some cases where adsorption has been reported that precipitation may have been responsible for the loss of calcium from solution. Commercial ammonium hydroxide often contains carbonates. Likewise an alkaline solution containing calcium when exposed to atmospheric carbon dioxide readily throws down calcium carbonate.

In the opinion of the writer, it is doubtful whether the calcium ion is adsorbed by either ferric or aluminum hydroxide in a neutral or very slightly acid solution. He agrees with those who believe that no error is introduced into a determination of calcium if double precipitation of the hydroxides of iron and aluminum is omitted and care is taken to rid the solution of ammonia. It is possible, however, that hydroxides other than those of iron and aluminum may carry down calcium when they are precipitated in its presence. It would

be interesting to determine this. It would seem logical to assume that magnesium would behave in the same way that calcium does, and the writer has done some work which indicates that this might be so, but further evidence must be obtained.

It may be said, of course, that calcium really has been lost from solution in all the foregoing experiments but that the loss was so small as to escape detection by the analytical methods used. This is true, but it is not felt that this invalidates the results from an analytical point of view. When results found in experiment 1 are omitted, it is found that out of 45 trials, 27 seemed to show slight negative loss and 18 positive or no loss. In most cases this loss is very small indeed and corresponds very closely to the experimental error. The average of all negative adsorption or gain is 0.00021 gm. of calcium, and the average of all positive losses is 0.00024 gm. of calcium. It is believed that there was no loss or gain in the concentration of the calcium ion when the hydroxides of iron and aluminum were precipitated. Both losses and gains were within the limits of experimental error, which was about $\pm$ 0.0002 gm. of calcium.

The precautions necessary to be sure that no calcium will come down with the hydroxides are the following:

1. The ammonium hydroxide should be free from carbonates.
2. In dissolving the sample, boil off all carbon dioxide.
3. After precipitating the aluminum and ferric hydroxides, boil off all the ammonia.

SUMMARY

The calcium ion is not appreciably adsorbed by the hydroxides of iron or aluminum when all ammonia is removed by boiling after these hydroxides have been precipitated.

The calcium ion is not appreciably adsorbed by the hydroxides of iron and aluminum if the solution is cooled with a stream of carbon dioxide after these hydroxides have been precipitated.

The presence of a moderate excess of ammonium hydroxide results in coprecipitation of calcium with the hydroxides.

If a solution is saturated with carbon dioxide after the precipitation of the iron and aluminum hydroxide and before they are filtered off, no loss of calcium from the solution will result.

The double precipitation of the hydroxides of iron and aluminum is unnecessary when calcium is being determined provided all ammonium hydroxide is removed from the solution and no ions that form insoluble compounds with calcium are present.

REFERENCES

(1) DAHR, 1923 *Kolloid Ztschr.* 33: 29.
(2) FALES, H. A. 1925 Inorganic Quantitative Analysis, ed. 1, p. 179. New York.
(3) HENDEL, J. M. 1926 Quantitative Analysis, ed. 1, p. 27. Boston and New York.

(4) MAHIN, E. G. 1924 Quantitative Analysis, ed. 3, p. 27. New York.
(5) SCHERINGA, K. 1918 Adsorption by colloidal hydroxides. *Pharm. Weekbl.* 55: 1070–1074.
(6) SMITH, G. M. 1917 Contamination of precipitates in gravimetric analysis: solid solution and adsorption vs. higher-order compounds. *Jour. Amer. Chem. Soc.* 39: 1152–1173.
(7) TALBOT, H. P. 1923 An Introductory Course of Quantitative Analysis, ed. 6, p. 128. New York.

A METHOD OF STUDYING THE ACTIVITY AND RATE OF DIFFUSION OF PROTOZOA AND BACTERIA IN THE SOIL

L. LOSINA-LOSINSKY AND P. F. MARTINOV

Scientific Meliorative Institute, Leningrad

Received for publication October 26, 1929

Nearly every contribution to the subject of soil protozoa begins with a reference to Russell's investigations (12). This author and his associates were the first to study the part protozoa play in the life of the soil. It is very important that Russell and Hutchinson (13) approached the question of the soil protozoa from a practical agricultural point of view, and suggested the so-called "protozoan theory" of soil fertility. These investigations stimulated further study of protozoa in the soil and aroused the interest of large circles of protozoölogists and microbiologists. However, this theory was somewhat one-sided and was subjected to considerable criticism by many authors; even the fact of the existence of active protozoa in the soil remained in doubt. This was explained by the absence of exact methods for detecting active protozoa in the soil, and for this reason all the deductions as to their significance were somewhat indefinite.

The methods of investigating the soil protozoa[1] can be divided into two groups: a direct study of protozoa in the soil; and an indirect method, consisting in the detection of protozoa through the use of cultures—in other words, by soil inoculation of special nutritive media. To the methods of direct investigation belong the experiments of Koffman (8, 9), Dogiel, Rammelmeier, and Strelkov (5), Mawrodiadi (11) and others. Koffman extracted protozoa from the soil by means of capillary attraction. For this purpose he employed objectives with different kinds of small cavities which contained a certain quantity of soil and water. When a cover-glass was placed on this glass, the protozoa were extracted from the soil through the capillary attraction. Dogiel and his assistants (5) detected the protozoa by preparing thin soil films. Mawrodiadi (11), by filtering the soil, demonstrated active forms in the filtrate. The real significance of the protozoa in the soil can hardly be judged, however, when based on such a study. The number of protozoa that were found in the soil by such means was generally insignificant; only occasionally were flagellata found in great numbers (5), and often whole groups of protozoa—ciliata and rhizopoda—were absent, for by these methods it is not possible to detect them.

[1] The descriptions of methods are given in the works of Kopeloff and Coleman (10), Sandon (14, 15), Severtzova (16), Yakimoff and Zeren (20), Waksman (19), and others.

The absorption of the protozoa by the soil, and the consequent difficulty of finding them, prove that an immediate detection of the protozoa is possible only when they are abundant. One could not prove by these means that protozoa are elements of natural soil population, therefore a whole group of investigators believe that protozoa appear as an occasional element among the soil population, and develop there only under very favorable conditions. The investigation of protozoa by means of cultures has the advantage that if the protozoa are in the soil even in very insignificant numbers, they can be easily detected after the inoculation of the nutritive medium by this soil.

The definition of active forms is based upon the count made after the soil inoculation on a nutritive medium (as a result of a series of dilutions), at first of the whole quantity of protozoa, and then of the cysts separately after the inoculation of the soil in which the active forms previously had been killed. The difference between both counts gives an idea of the number of active forms (2, 3). Such a method is used by most soil protozoölogists, but its defects are quite evident. The method is very inconvenient and requires many assistants; the fluctuations in the number of protozoa calculated by this method are so great that it is difficult to judge precisely the number of active forms. While antiseptics at a high temperature kill the active forms, they can influence partially even the cysts, killing less resistant cysts or suppressing their further development. Those species of protozoa which are not characteristic for the soil can develop, and, on the contrary, not all the species that live in the soil can develop on the artificial media generally used.

In the absence of exact methods of detecting the active protozoa in the soil, a group of investigators (1, 6, 18) would deny the part which is attributed to protozoa, and in general have doubts as to their active existence in the soil, especially the ciliata. The principal problem for soil protozoölogy, therefore, is the development of methods for detecting the degree of activity of protozoa in the soil. This article is a preliminary account of such an investigation.[2]

PROBLEMS OF INVESTIGATION

The following questions were considered: 1. Will the protozoa diffuse in the soil? 2. What can be the rate of diffusion?

We consider possible the solution of these questions in the following way. If one inoculates a small part of sterile soil with protozoa and bacterial culture or with an untreated soil, if the protozoa are active, they must spread over the soil taken for the experiment. This circumstance will be also a proof of their capacity to feed and to multiply in the soil. Naturally, the cysts are not capable of moving and consequently, if the possibility of water currents in the soil or of the mixing of the soil is excluded, they cannot diffuse in the soil.

[2] We are grateful to Prof. B. Polinov, in whose soil laboratory our work was done, for advice and help on the questions of soil science; and to Prof. V. Dogiel, who showed an interest in the present study, and gave us valuable suggestions.

METHOD

An ordinary cabbage garden soil was taken for the experiments. After having been air-dried, the soil was divided through sieves into a series of fractions containing particles of the following size: ∞ –0.1 mm., 0.1–0.25 mm., 0.25–0.5 mm. Then the soil was sterilized by dry heat at 140–150°C., after which petri dishes 12 cm., or in some experiments 16.5 cm., in diameter were filled with it. The weight of the soil put on the petri dishes—on the smaller, 50 gm. and on the larger, 94.6 gm.—was so calculated that a unit of space in all cases contained the same quantity of soil. The soil was moistened with sterile distilled water by stirring with a glass stick. After a few examinations the pH of the moistened soil was 6.6–6.7. Experiments were run with the soil at different moisture concentrations compared to an absolutely dry soil, which

TABLE 1

Changes in moisture content of soil fractions

	SOIL FRACTIONS								
	∞–0.1 mm.			0.1–0.25 mm.			0.25–0.5 mm.		
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Moisture concentration, compared to an absolutely dry soil:									
Before beginning experiment	15.0	20.0	25.0	15.0	20.0	25.0	15.0	20.0	25.0
End of experiment	14.2	18.8	24.4	14.4	19.6	23.9	14.5	19.1	24.3
Average	14.6	19.4	27.7	14.7	19.8	24.5	14.8	19.6	24.7
Average moisture content in per cent of water-holding capacity	27	36	46	32	42	52	35	47	59

The table shows that the moisture fluctuations during the experiments are very insignificant and hardly could have an influence upon the experiments.

gives a more accurate idea of the moisture than when compared to an air-dried soil. The moisture was determined before the experiments were begun as well as 8 days later, at the end of the observations. The data are set forth in table 1.

The petri dishes with a moistened soil were put into an autoclave, where a final sterilization was produced under a pressure of 2 atmospheres during 30 minutes.

After the petri dishes were cooled, into the very center of the dishes (fig. 1. *A*) a mixture of pure cultures of *Bact. radicicola*, amoebae (*Vahlkampfia*), and infusoria (*Colpoda steini*) was introduced by means of a platinum loop, after which the dishes were kept at 25°C. *B. radicicola* was isolated from clover. The protozoa were isolated from the soil of the test district of the Zolotaja Orda (Turkestan). The amoebae, as well as *C. steini*, in a mixture with *B. radicicola*, gave a very good growth on an agar medium of the following composition: soil extract[3]–1,000 cc., mannite–10 gm., K_2HPO_4–1 gm., agar–15 gm.

[3] The soil extract was prepared from the cabbage garden soil.

In order to take samples of the soil from definite parts of the petri dishes, short soldered glass capillaries were placed on the soil surface, beginning 1 cm. from the center and extending, at intervals of 1 cm., to the periphery (fig. 1).

Daily for 6 or 8 days, a few grains of soil were taken with a platinum spatula from every centimeter, beginning at the center. These samples were transferred to an agar medium, not simultaneously from every centimeter, but gradually from every two, beginning from the center, for the first problem was to establish the fact of the diffusion of microörganisms, and not the rate of diffusion. The petri dishes with the agar medium and the inoculated soil were also kept at 25°C.

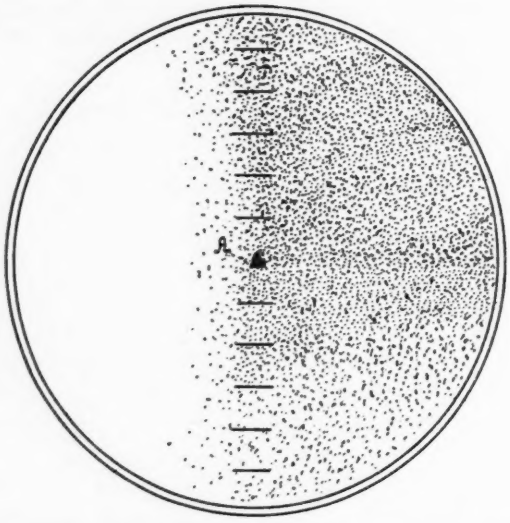


FIG. 1. ARRANGEMENT OF CAPILLARIES FOR FACILITATING THE TAKING OF SOIL SAMPLES

Two or three days after the soil from the experimental dishes had been inoculated, an examination of the agar medium was made in order to detect the cultures of protozoa and bacteria. Generally the examination on the fourth day and later was dispensable, because during the first days the presence or absence of protozoa and bacteria on the agar plate was evident. At the same time control observations, to prove the complete sterility of the soil, were made on a soil not inoculated with microörganisms.

DIFFUSION OF PROTOZOA AND B. RADICICOLA IN THE SOIL

In order to determine whether the protozoa and *B. radicicola* examined are active in the soil, the soil in the center of the dish was inoculated with cultures of these organisms, and the next day tests were made from the first and second

centimeter areas. During the following days such tests were made not only from the first centimeters, but also from the subsequent areas. These samples were transferred to an agar plate. Two series of experiments were carried out, for which three fractions of soil were taken, each with a moisture content of 15, 25, and 35 per cent. Observations made during 6 days, gave results

TABLE 2

Diffusion of bacteria and protozoa in soil containing 15 per cent moisture

DISTANCE FROM CENTER	SERIES I							SERIES II						
	Experiment number	1st day	2d day	3d day	4th day	5th day	6th day	Experiment number	1st day	2d day	3d day	4th day	5th day	6th day
Fraction ∞–0.1 mm.														
cm.														
I	1	—	—	BAC			BC	9	B	B	BA	BA	BA	BA
II		—	—	—	B	—	B		—	—	B	B	B	B
III		—	—	—	B	—	B		—	—	—	B	B	B
IV		—	—	—	—	—	—		—	—	—	B	B	B
V		—	—	—	—	—	—		—	—	—	—	B	B
VI		—	—	—	—	—	—		—	—	—	—	—	—
Fraction 0.1–0.25 mm.														
I	2	B	B	B	B	B	B	10	—	BA	B	BA	BA	BA
II		—	—	—	—	—	—		—	B	B	BA	BA	BA
III		—	—	—	—	—	—		—	—	B	B	B	B
IV		—	—	—	—	—	—		—	—	B	B	B	B
V		—	—	—	—	—	—		—	—	—	—	B	B
VI		—	—	—	—	—	—		—	—	—	—	B	B
Fraction 0.25–0.5 mm.														
I	3	BAC	BA	BA	BA	BAC	BA	11	B	B	B	B	B	BC
II		—	—	B	B	B	BA		B	B	B	B	B	B
III		—	—	B	B	B	B		—	—	B	B	B	B
IV		—	—	B	B	B	B		—	—	B	B	B	B
V		—	—	—	—	B	B		—	—	—	—	B	B
VI		—	—	—	—	B	B		—	—	—	—	B	B

* Distance from the center.

† B = *Bact. radicicola.* A = Amoebae (*Vahlkampfia*). C = Ciliates (*Colpoda steini*).

that proved that the bacteria and protozoa diffuse energetically in the soil, moving from the center to the periphery of the petri dishes. At first the protozoa and bacteria are seen only in the vicinity of the place of inoculation; then they appear farther away, gradually reaching the brim of the dish (tables 2, 3, 4).

Tables 2, 3, and 4 show that the activity of bacteria and protozoa depends, first, upon the degree of soil moisture, and, second, upon the mechanical structure of the soil. When the soil has a moisture content of 15 per cent, the activity of protozoa and bacteria is not great. The diffusion of *B. radicicola* takes place on the fifth or sixth day, but in two cases (experiments 1 and 2) bacteria diffused only in the area 1 cm. from the center, or were seen at a

TABLE 3

Diffusion of bacteria and protozoa in soil containing 25 per cent moisture

DISTANCE FROM CENTER	SERIES I							SERIES II						
	Experiment number	1st day	2d day	3d day	4th day	5th day	6th day	Experiment number	1st day	2d day	3d day	4th day	5th day	6th day
						Fraction ∞–0.1 mm.								
cm.														
I	4	BA	BA	BAC	BAC	BAC	BAC	12	BA	BAC	BAC	BAC	BAC	BAC
II		B	B	BAC	BAC	BAC	BAC		B	BA	BAC	BAC	BAC	BAC
III		—	B	BAC	BAC	BAC	BA		—	B	BA	BAC	BAC	BAC
IV		—	—	BA	BAC	BA	BA		—	—	BA	BAC	BAC	BAC
V		—	—	B	BA	BA	BA		—	—	—	—	BAC	BAC
VI		—	—	—	B	B	B		—	—	—	—	BAC	BAC
						Fraction 0.1–0.25 mm.								
I	5	BAC	BAC	BAC	BAC	BAC	BAC	13	BAC	BAC	BAC	BAC	BAC	BAC
II		BAC	BAC	BAC	BAC	BAC	BAC		BAC	BAC	BAC	BAC	BAC	BAC
III			BAC	BAC	BAC	BAC	BAC			BAC	BAC	BAC	BAC	BAC
IV				BAC	BAC	BAC	BAC		—		BAC	BAC	BAC	BAC
V		—	—		BAC	BAC	BAC		—	—	B	BAC	BAC	BAC
VI		—	—		BAC	BAC	BAC		—	—	—	B	BAC	BAC
						Fraction 0.25–0.5 mm.								
I	6	BAC	BAC	BAC	BAC	BAC	BAC	14	BA	BAC	BAC	BAC	BAC	BAC
II		BAC	BAC	BAC	BAC	BAC	BAC		BA	BA	BAC	BAC	BAC	BAC
III				BAC	BAC	BAC	BAC				BAC	BAC	BAC	BAC
IV		—	—	BAC	BAC	BAC	BAC				BAC	BAC	BAC	BAC
V		—	—		BAC	BAC	BAC		—	—		BAC	BAC	BAC
VI		—	—	—	BAC	BAC	BAC		—	—	—	B	B	BAC

distance of 3 to 4 cm. only on some days of the experiment. As the diffusion of bacteria and protozoa always took place gradually from the center of the place of inoculation to the periphery, such blanks could be explained only by an insignificant content of bacteria in this part of the soil. When the soil grains were taken with a platinum spatula, the bacteria and protozoa were not always taken with them. The control experiments on a sterile soil proved that

the sterilization completely destroyed the soil population, and in the aforementioned cases there was no place for an occasional survival of bacterial spores or protozoan cysts. Amoebae in a soil containing 15 per cent moisture, possess a certain activity. Only in a few cases (experiment 3, 9, and 10) did amoebae diffuse on a radius of 2 cm. Experiments 2 and 11 showed that they could be detected only in the place of inoculation. The other experiments showed that they appear within a radius of 1 cm.

For the activity of infusoria, as one may suppose, a priori, a greater moisture content is required than for that of the bacteria and other protozoa. A

TABLE 4

Diffusion of bacteria and protozoa in soil containing 35 per cent moisture

DISTANCE FROM CENTER	SERIES I					SERIES II				
	Experiment number	1st day	2d day	3d day	4th day	Experiment number	1st day	2d day	3d day	4th day
				Fraction 0.1–0.25 mm.						
cm.										
I		BA	BAC	BAC	BAC		BAC	BAC	BAC	BAC
II		BA	BAC	BAC	BAC		BAC	BAC	BAC	BAC
III	7		BAC	BAC	BAC	15		BAC	BAC	BAC
IV		—		BAC	BAC		—		BAC	BAC
V		—	—		BAC		—	—		BAC
VI		—	—	—	BAC		—	—	—	BAC
				Fraction 0.25–0.5 mm.						
I		BAC	BAC	BAC	BAC		BAC	BAC	BAC	BAC
II		BAC	BAC	BAC	BAC		BAC	BAC	BAC	BAC
III	8		BAC	BAC	BAC	16		BAC	BAC	BAC
IV		—		BAC	BAC		—		BAC	BAC
V		—	—		BAC		—	—		BAC
VI		—	—	—	BAC		—	—	—	BAC

moisture content of 15 per cent in the given soil is evidently near the limit at which the diffusion of infusoria *Colpoda steini* is possible.

In a soil with 25 per cent moisture the result is quite different. The activity of bacteria and protozoa is so great that within 4 days the whole petri dish with the soil is inoculated by microörganisms. In this respect, 35 per cent moisture content makes no substantial difference, as can be seen in table 4.

Series I and II of the experiments show that *B. radicicola* always are the first to diffuse; after which generally come the amoebae, followed by the infusoria. In some cases, however, *Colpoda steini* diffuse with the same velocity as the amoebae, and sometimes even more quickly. This can be observed only at a high soil moisture content (25 to 35 per cent). The mechanical structure

TABLE 5

Diffusion of bacteria and protozoa in soil containing 15, 20, and 25 per cent moisture

DISTANCE FROM CENTER	FRACTION ∞ 0.1 MM.									FRACTION 0.1–0.25 MM.									FRACTION 0.25–0.5 MM.								
	Experiment number	1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day	Experiment number	1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day	Experiment number	1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day
15 per cent moisture																											
cm.																											
I	17	—	—	—	—	—	—	—	—	18	B	B	B	BA	BA	BA	BA	BA	19	—	BA	BA	BA	BA	BA	BA	BA
II		—	—	—	—	—	—	—	—		—	B	B	B	B	B	B	BA		—	—	—	BA	—	—	—	—
III		—	—	—	—	—	—	—	—		—	—	—	—	—	—	B	B		—	—	—	B	—	—	—	—
IV		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	B		—	—	—	B	—	—	—	—
V		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—
VI		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—
20 per cent moisture																											
I	20	—	—	—	—	—	—	—	—	21	B	BA	BA	BA	BA	BAC	BAC	BAC	22	B	BA	BA	BA	BA	BA	BA	BA
II		—	—	—	—	—	—	—	—		—	B	B	BA	BA	BA	BAC	BAC		—	BA	BA	BA	BA	BA	BA	BA
III		—	—	—	—	—	—	—	—		—	B	B	B	BA	BA	BA	BA		—	B	B	B	B	B	B	BA
IV		—	—	—	—	—	—	—	—		—	—	B	B	B	BA	BA	BA		—	B	B	B	B	B	B	B
V		—	—	—	—	—	—	—	—		—	—	—	B	B	B	B	BA		—	—	B	B	B	B	B	B
VI		—	—	—	—	—	—	—	—		—	—	—	—	B	B	B	B		—	—	—	B	B	B	B	B
25 per cent moisture																											
I	23	B	BA	BA	BA	BA	BA	BA	BA	24	BAC	BAC	BAC	BAC	BAC	BAC	BAC	BAC	25	BAC	BAC	BAC	BAC	BAC	BAC	BAC	BAC
II		—	—	—	—	—	—	—	—		B	B	B	B	BA	BAC	BAC	BAC		BC	BAC	BAC	BAC	BAC	BAC	BAC	BAC
III		—	—	—	—	—	—	—	—		—	B	B	B	BA	BA	BA	BA		BC	BAC	BAC	BAC	BAC	BAC	BAC	BAC
IV		—	—	—	—	—	—	—	—		—	B	B	B	B	B	BA	BA		B	BC	BC	BAC	BAC	BAC	BAC	BAC
V		—	—	—	—	—	—	—	—		—	B	B	B	B	B	B	B		B	BC	BC	BC	BAC	BAC	BAC	BAC
VI		—	—	—	—	—	—	—	—		—	—	B	B	B	B	B	B		B	BC	BC	BC	BC	BAC	BAC	BAC
VII		—	—	—	—	—	—	—	—		—	—	B	B	B	B	B	B		—	BC	BC	BC	BC	BC	BC	BAC
VIII		—	—	—	—	—	—	—	—		—	—	B	B	B	B	B	B		—	BC	BC	BC	BC	BC	BC	BC

B = *Bact. radicicola*, A = Amoebae (*Vahlkampfia*). C = *Colpoda steini*.

of the soil has an influence on the degree of activity, but this question will be discussed hereafter.

RATE OF DIFFUSION OF B. RADICICOLA AND PROTOZOA IN THE SOIL

By making tests of the soil daily, and simultaneously from all parts of the petri dishes (on a radius of 6 to 8 cm.), one can obtain an idea of the velocity of diffusion of microörganisms in the soil, judging by the distance they have traveled during 24 hours.

The rate of diffusion was studied in series I and II in connection with the moisture and mechanical structure. Both series showed that the activity of the microörganisms in a soil of 25 and 35 per cent moisture content is nearly the same; at 15 per cent it is considerably lowered. In order to make clear the relation between the gradual rate of diffusion and the moisture content, observations were made on soils containing, 15, 20, and 25 per cent moisture. The experiments were carried out during 8 days, and gave the results reported in table 5 and in figures 2, 3, 4, and 5.

The data indicate that the quantity of moisture and the mechanical structure of the soil play a large part in the rate of diffusion of bacteria and protozoa in the soil. Let us examine this indication, from the standpoint of the different soil fractions.

Fraction ∞–0.1 mm.—In the third series of experiments, at a moisture content of 15 and 20 per cent, the soil remained sterile, whereas in the experiments of series I and II, the bacteria and protozoa were detected at a certain distance from the center. At a minimum soil moisture content of 25 per cent bacteria and protozoa began to diffuse, but they did not move farther than 1 cm. from the center of the dish.

Fraction 0.1–0.25 mm.—This fraction gives an extremely precise idea of the rate of diffusion of the protozoa and bacteria. At a soil moisture content of 15 per cent, bacteria reached 2 cm. on the second day and 4 cm. on the eighth day (fig. 2). In a soil containing 20 per cent water, the rates of diffusion is remarkably quickened. The bacteria on the first day having populated soil in the periphery of 1 cm. from the place of inoculation, on the second day diffuse as far as 3 cm., and on the fifth occupy the whole surface of the petri dishes (fig. 3). At a soil moisture content of 25 per cent their rate of diffusion was still more heightened; on the fourth day all the surface of the soil was populated by them (fig. 4). The amoebae propagate in the same proportion but at a slower rate. At a soil moisture content of 15 per cent, amoebae were found at a distance of 1 cm. on the fourth day, and at a distance of only 2 cm. on the eighth day (fig. 2).

In a soil with a moisture content of 20 per cent, amoebae appeared on the second day at a distance of 1 cm., and reached 5–6 cm. on the eighth day. It is necessary to note in this experiment an extreme successiveness in the diffusion of amoebae, which moved 1 cm. during 24 hours (fig. 3). At a soil moisture content of 25 per cent, amoebae developed on 1 cm. on the first day; on the

fifth day they occupied the soil surface within a radius of 3 cm.; and on the eighth of 5 cm. (fig. 4).

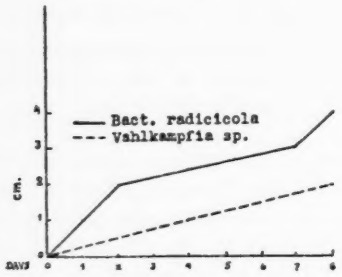


FIG. 2

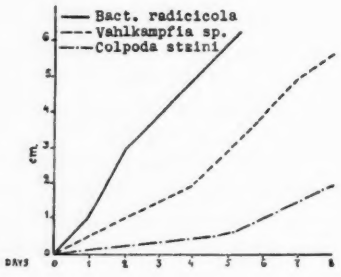


FIG. 3

FIG. 2. THE RATE OF DIFFUSION OF PROTOZOA AND BACTERIA IN THE SOIL
Fraction 0.1–0.25 mm. with 15 per cent moisture (32 per cent of water-holding capacity)

FIG. 3. THE RATE OF DIFFUSION OF PROTOZOA AND BACTERIA IN THE SOIL
Fraction 0.1–0.25 mm. with 20 per cent of moisture (42 per cent of water-holding capacity)

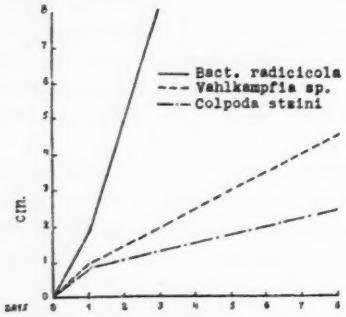


FIG. 4

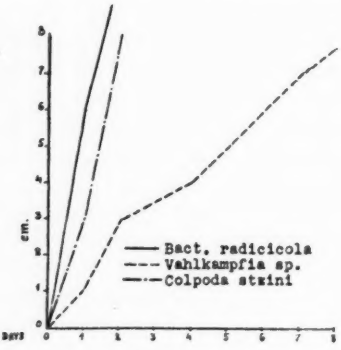


FIG. 5

FIG. 4. THE RATE OF DIFFUSION OF PROTOZOA AND BACTERIA IN THE SOIL
Fraction 0.1–0.25 mm. with 25 per cent moisture (52 per cent of water-holding capacity)

FIG. 5. THE RATE OF DIFFUSION OF PROTOZOA AND BACTERIA IN THE SOIL
Fraction 0.25–0.5 mm. with 25 per cent of moisture (59 per cent of water-holding capacity)

The infusoria act in a somewhat different way. At a soil moisture content of 15 per cent they could not be observed in the soil, but with the increase of moisture to 20 per cent, *Colpoda steini* began to develop very slowly in the soil, reaching 1 to 2 cm. only on the sixth or seventh day (fig. 3). When the

moisture was 25 per cent, the *Colpoda steini* began to develop at the same time as the bacteria and amoebae, but they did not diffuse farther than 2 cm. during 8 days (fig. 4).

Fraction 0.25–0.5 mm.—In this fraction, bacteria diffused somewhat more quickly than in the 0.1–0.25 mm. fraction at the same moisture content. Amoebae at a moisture content of 15 per cent do not reach more than 2 cm. from the center, and 20 per cent develop on the second day to the 2 cm. area, but on the eighth day reach 3 cm. In a soil with a moisture content of 25 per cent, one observes an extremely gradual movement of amoebae, about 1 cm. in 24 hours (fig. 5). Ciliates were not discovered at all at 15 and 20 per cent moisture, but at a moisture content of 25 per cent their diffusion was noted as extremely rapid. After 24 hours they had reached 3 cm. from the center, and a day afterward they were found in the whole soil of a dish 16.5 cm. in diameter (fig. 5).

These data show that when equal quantities of water are added to an absolutely dry soil, the rate and character of diffusion of protozoa and bacteria in different soil fractions are not the same. First one must consider the different water-holding capacities of the fractions. The greatest water-holding capacity exists in the fraction ∞–0.1 mm. (table 1); consequently this fraction contains less physiologically accessible water. Up to a moisture content of almost 40 per cent of the full water-holding capacity, protozoa either will not populate the soil, or will do it very slowly. But with a greater amount of moisture which is physiologically accessible in a fraction containing larger grains in addition to a decreased water-holding capacity, the activity of bacteria and protozoa becomes much greater. A very striking example is presented in the experiment with the 0.25–0.5 mm. fraction, in which a moisture content of 59 per cent the water-holding capacity has allowed the infusoria to diffuse over 191 cm. in 2 days.

Fractions have not only different water-holding capacities, but also different chemical and physico-chemical properties. These conditions evidently have an influence upon the character and rate of diffusion of protozoa and bacteria. In one case, the moisture content of the 0.25–0.5 mm. fraction is the same as that of the ∞–0.1 mm. fraction (35 and 36 per cent of their water-holding capacity), but in the first fraction the bacteria and amoebae diffuse, but in the second the soil remains sterile. Experiments 21 and 23 demonstrate this fact as well. In experiment 21 a diffusion of all the groups of microörganisms takes place over the petri dish, whereas in experiment 23, amoebae and bacteria have populated only a region with a radius of 1 cm., notwithstanding that the moisture was greater here. We suppose that in fine-structured soils, which possess a greater water-holding capacity, the diffusion of microörganisms is impeded by an absence of large spaces between the soil particles and by a great soil surface, which makes the distance greater. This statement must apply especially to ciliates, which are swimming forms.

Waksman (19) has considered the importance of soil structures and of soil

substance (quantity of humus) in relation to protozoan activity in the soil. As has been said already, the rate of diffusion of bacteria and of different types of protozoa is not the same,[4] but depends upon different rates of multiplication, the rapidity of the progressive movement, and, possibly, also upon unequal values of the medium as a nutritive substrate for protozoa.

The multiplication of amoeba is more rapid than that of *Colpoda steini*, but the progressive movement is less rapid. At a water-holding capacity of from 25 to 35 per cent, the rate of diffusion of amoeba is more or less the same and presents, first of all, a function of multiplication. For the infusoria, the factor of moisture is, further, important because with their multiplication and increased water-holding capacity their progressive movement grows more rapid, and they can populate the given volume of soil more rapidly. The fact that the protozoa follow the bacteria is quite evident, for the bacteria serve as a food for the protozoa. The diffusion of protozoa in sterile media (without bacteria) or in media with bacteria that are not a nutritive source is hardly possible (17).

Our method gives a concrete idea of the degree of protozoan activity in the soil. In connection with this, it is interesting to compare our results with the data obtained by different investigators through direct examination of active forms under the microscope.

In the active state, flagellates were the forms most often found in the soil. They were discovered in a soil containing moisture of 11 per cent of its full water-holding capacity (18), at 4 to 6 per cent [Cercomonas (4)], and at 13 to 14 per cent moisture, compared to an air-dried soil (16). In soils with a similar content of water the other protozoa, according to the data of these investigators, were encysted. Sherman (18), Goodey (16), and Alexeieff (1), in general find that most of the protozoa, especially ciliates, found in a normal soil are in an encysted state. Somewhat unexpected and interesting data were obtained by Jwao Hino (7). This author, by directly investigating the soil under the microscope, detected large ciliata in the sandy soils containing 10.8 per cent water (26 per cent of water-holding capacity), small ciliata at 8.2 per cent (20 per cent of water-holding capacity), and still smaller ciliata at 7.1 per cent (*Colpoda saprophilia*). We regret that a detailed description of Jwao Hino's method is unavailable to us (because it is published in the Japanese language), but his data agree closely with ours. The minimum moisture at which *Colpoda steini* developed, in our experiments, corresponded to 27 per cent of the water-holding capacity. One must consider that the soils Jwao Hino and we were dealing with were quite different, and that the structure of the soil has an influence upon the activity of soil protozoa.

SUMMARY

Amoebae (*Vahlkampfia*) and ciliates (*Colpoda steini*) exist in the soil in an active state. After the center of petri dishes containing sterile soil have been

[4] This circumstance can be used for rapidly obtaining pure cultures of protozoa.

inoculated with cultures of protozoa mixed with *Bact. radicicola* these organisms diffuse from the place of inoculation to the periphery of the petri dish. The detection of protozoa some time afterward at a considerable distance from the place of inoculation shows that they are living in the soil and can move freely in it.

These species of protozoa and *B. radicicola* were found to multiply rapidly in the soil used. The following circumstance proves this statement: the introduction of one loop of the culture into sterile soil is sufficient to inoculate, within a few days, the whole volume of soil in the dish with protozoa; the smallest quantity of the soil taken from any part of the dish would then give a rich culture of protozoa on the agar plate within two or three days.

The activity and rate of diffusion of bacteria and protozoa in the soil depend, first of all, upon the moisture and the mechanical structure of the soil. At a moisture content of from 15 to 20 per cent (25 to 40 per cent of the water-holding capacity) bacteria and amoebae are in an active state, but diffuse slowly in the soil, whereas *Colpoda steini*, in most cases, does not diffuse in the soil farther than 1 cm. from the place of inoculation. At a soil moisture content of more than 20 per cent all protozoa are extremely active and diffuse rapidly through the whole soil.

When the moisture content of the soil is comparatively small, amoebae diffuse more rapidly than ciliates, but at a greater moisture content (more than 60 per cent of the water-holding capacity) the infusoria move more rapidly than the amoebae.

Bacteria, in their progressive movement, always precede the protozoa, the bacteria (*B. radicicola*) serving as a source of food for the protozoa.

REFERENCES

(1) ALEXEIEFF, A. 1925 A propos des Protozoaires du sol: existent-ils réelement? *Coproprotistologie. Arch. Russ. Protist.* 4: 1–2.

(2) CUTLER, D. W. 1920 A method for estimating the number of actual protozoa in the soil. *Jour. Agr. Sci. (England)* 10: 136–143.

(3) CUTLER, D. W., CRUMP, L. U., AND SANDON, H. 1922 A quantitative investigation of the bacterial and protozoa population of the soil. *Phil. Trans. Roy. Soc. (London) Ser. B.* 211: 317–350.

(4) CUTLER, D. W., AND DIXON, H. 1927 The effect of soil storage and water content of protozoan population. *Ann. Appl. Biol.* 14.

(5) DOGIEL, V., RAMMELMEIER, E., AND STRELKOV, A. 1927 On the methods of studying soil protozoa. Inst. Exp. Agron., Leningrad. *Bul. Bur. Agr. Microbiol.* 2: 155–170 and 209.

(6) GOODEY, T. 1915 Protozoa in relation to soil bacteria. *Proc. Roy. Soc. (England) Ser. B* 88: 437–456.

(7) JWAO, HINO 1926 Active ciliates in the soil. *Jour. Sci. Agr. Soc. (Japan)*, No. 289 (angl. résumé).

(8) KOFFMAN, M. 1926 Beiträge zur Kenntnis der Bodenprotozoen. *Acta Zool.* 7: 277–328.

(9) KOFFMAN, M. 1928 Eine Methode zur direkten Untersuchung der Mikrofauna und Mikroflora des Bodens. *Centbl. Bakt.* (II) 75: 28–44.

(10) KOPELOFF, N., LINT, H. C., AND COLEMAN, D. A. 1916 A review of investigations on soil protozoa and soil sterilization. *Centbl. Bakt.* (II) 46: 28–74.

(11) MAWRODIADI, P. A. 1925 Zur Forschungsmethodie der Boden microfauna. *Mem. Inst. Agr. Forest. Belarussie,* 9: 3–7.

12) RUSSELL, E. 1915 Soil protozoa and soil bacteria. *Proc. Roy. Soc. (England) Ser. B* 89: 76–82.

(13) RUSSELL, E., AND HUTCHINSON, H. B. 1909, 1913. The effect of partial sterilization of soil on the production of plant food. *Jour. Agr. Sci. (England)* 3: 111–144; 5: 152–221.

(14) SANDON, H. 1927 Methods of investigation of protozoa (Russian). Bul. Sci. Meliorat. Inst. (Leningrad).

(15) SANDON, H. 1927 The Composition and Distribution of the Protozoan Fauna of the Soil. Biological Monographs and Manuals. Edinburgh and London.

(16) SEVERTZOVA, L. B. 1924 Method of counting culture medium, and pure cultures of soil amoebae. *Centbl. Bakt.* (I) 92: —.

(17) SEVERTZOVA, L. B. 1928 The food requirement of soil amoebae with reference to their interrelation with soil bacteria and soil fungi. *Centbl. Bakt.* (II) 73: 162–179.

(18) SHERMAN, J. U. 1914 The number and growth of protozoa in soil. *Centbl Bakt.* (II) 41: 625–630.

(19) WAKSMAN, S. A. 1916 Studies on soil protozoa. *Soil Sci.* 1: 135–152.

(20) YAKIMOFF, W. L., AND ZEREN, S. 1925 Contribution à l'étude des protozoaires des soils de Russie. *Centbl. Bakt.* (II) 63: 33–57.

THE EFFECT OF ALFALFA AND SWEET CLOVER ROOTS AND TOPS ON CARBON DIOXIDE EVOLUTION AND ACCUMULATION OF NITRATES IN THE SOIL

THOMAS L. MARTIN

Brigham Young University

Received for publication October 26, 1929

A study of the rate of decomposition of various organic materials has occupied the attention of many investigators of late years. Legumes as compared with non-legumes have received especial attention. Considerable interest has been evinced regarding the fertility value of legumes, particularly alfalfa and sweet clover (2, 4, 6). Carbon dioxide evolution and nitrate accumulation are commonly used as a measure of the rate at which these materials have decomposed into forms available for plant use. Using these indicators, the author (4) found that alfalfa roots decomposed more readily than did sweet clover roots. Little work, however, has been done in comparing the rate of decomposition of the tops with the roots of these legumes. How do sweet clover and alfalfa plants compare in rate of decay when the roots and tops are incorporated separately with the soil? How would the results compare if the roots and tops were mixed and incorporated with the soil? To answer these questions the following experiments were planned and carried through, carbon dioxide evolution and nitrate accumulation being used as a measure of the rate of decomposition.

PLAN OF EXPERIMENT

Experiment 1

A clay loam soil having a pH of 7.5 was obtained at a depth of 6 feet in the spring of 1928, and was left exposed until September, 1928. At that time, no plant material had obtained a foothold. Very slight summer showers were all the moisture which the soil had received. The surface 2 inches of a pile of this soil was removed, and the soil used for the experiment was taken from this depth down to 12 to 18 inches. For the nitrate studies 1-gallon glazed jars were filled with this soil, and 1 per cent of air-dried ground alfalfa roots having a total nitrogen content of 1.33 per cent was added to each of three jars. Similar jars of soil were treated with corresponding amounts of dried and ground alfalfa tops, sweet clover tops, and sweet clover roots. The nitrogen content of these substances was 2.25 per cent, 2.30 per cent, and 0.77 per cent respectively. Three jars of soil were used as controls. The alfalfa roots were obtained to a depth of 12 inches from a 5-year-old alfalfa field and the tops were

taken from the first crop at about the half-mature stage. The sweet clover roots were obtained to a depth of 12 inches from a second-year growth of sweet clover; the tops were approximately one-third grown. After these legumes were added, the moisture content of the soils was brought to 25 per cent dry basis. All the jars were kept under laboratory conditions at room temperatures varying from 19° to 21°C.

At intervals of 1, 3, 5, 7, 10, 13, and 16 weeks, the soils were sampled and nitrates were determined according to the phenol di-sulfonic acid method. The results are shown in figure 1.

The figure indicates that during the first five or six weeks, the alfalfa tops decomposed, or at least made nitrogen available more rapidly than did the other treatments. A very rapid increase in nitrates of the soils treated with sweet clover tops began after the fifth week, and from the seventh to the twelfth week these soils were the richest in the experiment. As determined in the

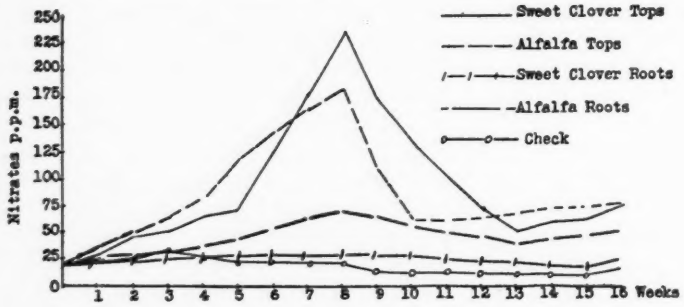


FIG. 1. NITRATES ACCUMULATED DURING A 16-WEEK PERIOD AFTER BEING INCORPORATED WITH 1 PER CENT QUANTITIES OF DIFFERENT KINDS OF ORGANIC MATTER

nitrogen analysis, the C-N ratio of the sweet clover tops was slightly narrower than that of alfalfa tops, and much narrower than that of the roots. If we accept the conclusions of previous experimentors (3, 7, 8, 9) on the influence of the C-N ratio on nitrate accumulation, the ammonia of the sweet clover should be available for nitrification more quickly than that of alfalfa, because the ratio is wider for alfalfa. This expectation does not appear in the present experiment until after the fifth-week period.

There is the possibility that the type of microorganisms growing in the soil account for this discrepancy. The author (5) found from a study of the influence of the media used in this experiment on the types of molds which develop, that the development of Mucor in the case of the tops was very vigorous during the first few weeks. Both the alfalfa and the sweet clover top treatments developed so many Mucors in three days that it was impossible to make plate counts. The sweet clover top treatments were more abundantly and vigorously supplied with Mucors than were the alfalfa-treated ones. At the

end of five weeks the Mucors had very appreciably decreased, and they continued to decrease until the tenth week, when the experiment ended.

In the present experiment the rapid increase in nitrates begins at about the period when the most vigorous growth of Mucors subsided in the former experiment. Whether these organisms actually use the nitrogen being evolved by the nitrifying organisms, or whether they merely check the activities of these bacteria is a question, but the present results indicate that some such relationship might exist. This would make clear why the C-N theory of nitrogen accumulation holds only after a period of several weeks.

The nitrate development in the root-treated soils does not show a discrepancy with the C-N theory, for the soil treated with alfalfa roots, which has the narrower ratio, is higher at all times than are the sweet clover root soils. This would be expected if the cause of the discrepancy in the tops is due to Mucor development, since the Mucors are at all times only a minor part of the fungi working on roots. It would also help to explain why so little nitrate accumulation occurred in the sweet clover soils, because Mucors are more abundant on sweet clover roots than on alfalfa roots, and the Mucors may have used a considerable portion of the small amount of nitrates in the root-treated soils.

If this explanation of the discrepancy with the sweet clover tops is accepted, the rest of the results agree very well with the C-N ratio theory. At eight weeks, the four treatments agree with the theory in that sweet clover tops, alfalfa tops, alfalfa roots, and sweet clover roots align themselves somewhat in proportion to their corresponding C-N ratios.

Experiment 2

The same types of soil and of organic matter were used in studying the rate of evolution of carbon dioxide. One-hundred-gram portions of soil were placed in 500-cc. Erlenmeyer flasks. One per cent quantities of air-dried alfalfa tops were added to each of two flasks. Similar flasks in groups of two were treated with corresponding quantities of alfalfa roots, sweet clover tops, and sweet clover roots. Two flasks were used as checks. The moisture content of the soil was brought to a 25 per cent dry basis. All flasks were kept under laboratory conditions at room temperatures. The amount of carbon dioxide evolved daily from each of these soils was determined every 24 hours for a period of 21 days. The apparatus used to determine carbon dioxide evolved was similar to that described by Waksman (10). A stream of CO_2-free air was drawn through the flasks into standard potassium hydroxide for a period of 20 minutes every 24 hours. Carbon dioxide was determined by titration according to the method described by Emerson (1). The results are given in figure 2.

It will be noted that in the relative positions of the various treatments the carbon dioxide evolution rate is somewhat similar to that indicated in the nitrate curve of figure 1. The tops decompose more rapidly than do the roots. The sweet clover tops evolved carbon dioxide faster than did the alfalfa tops during the first 3 days, and again after 14 days. The alfalfa root treatments

are surpassed by the sweet clover treatments during the first six days, but after that period the alfalfa root treatment leads.

Why is there not a uniform difference between the rate of decay of these materials based upon the C-N ratio content? There are a number of possible

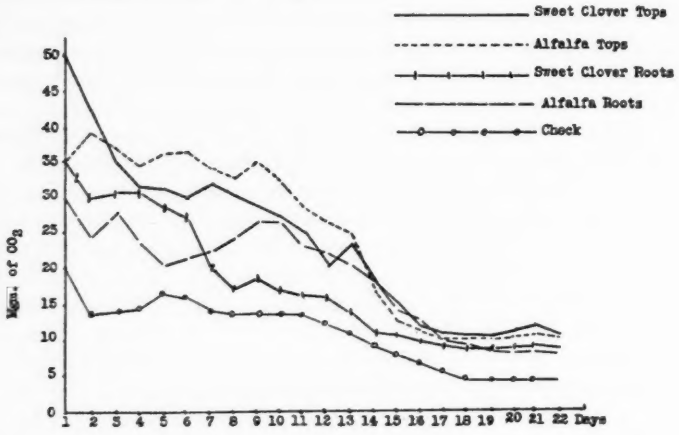

Sweet Clover Tops
Alfalfa Tops
Sweet Clover Roots
Alfalfa Roots
Check
Mgm. of CO_2
0 5 10 15 20 25 30 35 40 45 50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 Days

FIG. 2. AMOUNT OF CARBON DIOXIDE EVOLVED DAILY OVER A 22-DAY PERIOD FROM SOIL TREATED WITH 1 PER CENT QUANTITIES OF DIFFERENT KINDS OF ORGANIC MATTER

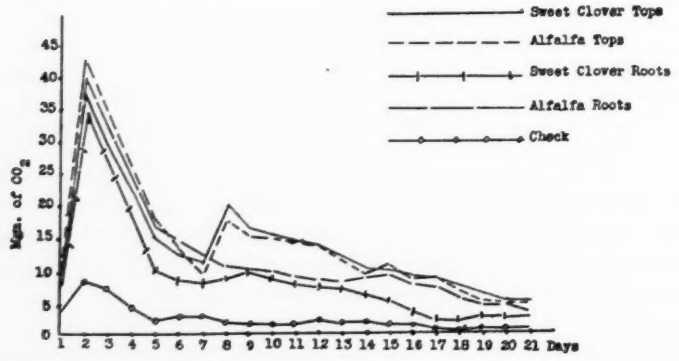

Sweet Clover Tops
Alfalfa Tops
Sweet Clover Roots
Alfalfa Roots
Check
Mgm. of CO_2
0 5 10 15 20 25 30 35 40 45
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 Days

FIG. 3. AMOUNT OF CARBON DIOXIDE EVOLVED DAILY OVER A 21-DAY PERIOD FROM SOIL TREATED WITH 1 PER CENT QUANTITIES OF DIFFERENT KINDS OF ORGANIC MATTER

explanations. One is the indefinite end point, as explained by Emerson (1). Again the air-dried material after being coarsely ground was passed through a 2-mm. sieve. Is it not possible that the more succulent material when dried and ground would be in a more finely divided state, and when passed through

the 2-mm. sieve there would be a tendency for the substances used for analysis to be more equal in decomposable ability?

To study the influence of fineness on carbon dioxide evolution another experiment was carried on in which the organic materials were passed through a 1-mm. sieve. The results are given in figure 3. It will be noted that there was a very rapid evolution of carbon dioxide from all four of the substances added, and that there was a noticeable tendency toward an equal decomposable ability, as evidenced by carbon dioxide evolution during the first six days. After that time, however, the rate was much slower. It would appear from figures 2 and 3 that the relative fineness of the organic materials studied is a factor to be considered when studies of this kind are being made.

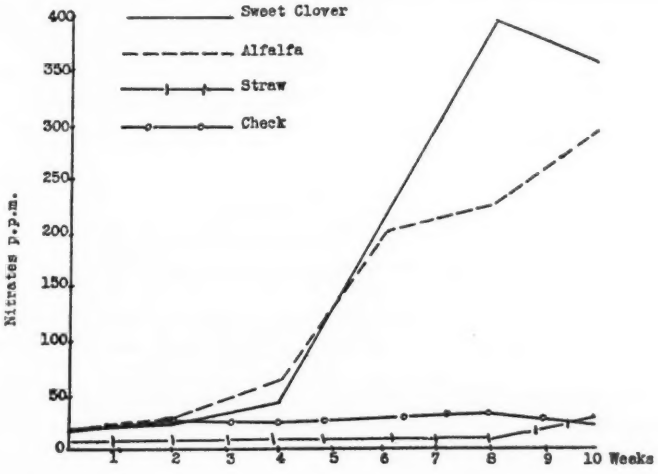


FIG. 4. NITRATES ACCUMULATED DURING A 10-WEEK PERIOD AFTER BEING INCORPORATED WITH 1 PER CENT QUANTITIES OF DIFFERENT KINDS OF ORGANIC MATTER

As was noted in figure 3, after the first seven days the order of carbon dioxide evolution is: sweet clover tops first, then alfalfa tops, although the difference is almost negligible. Following come alfalfa roots and sweet clover roots, although the differences again are very small in some cases. It would appear, in general, from figures 2 and 3 that the narrower the C-N ratio the more readily does the material decompose, as evidenced in the evolution of carbon dioxide. As in experiment 1, the discrepancies may be due to the differences in the decomposing organisms at work. The changes occur somewhat as the changing relationship of the organisms in the previous experiment might indicate.

Experiment 3

To study the influence of a mixture of tops and roots on carbon dioxide and nitrate accumulation 1-kgm. portions of the same soil as was used previously

were added to 2-quart fruit jars; 70 per cent quantities by weight of ground alfalfa tops and 30 per cent by weight of ground roots were mixed and 1 per cent quantities in turn mixed with the soil. The moisture was kept at 25 per cent dry basis. The same study was made with a mixture of sweet clover roots and tops, and a third study was made with 1 per cent quantities of wheat straw. At intervals of 2, 4, 6, 8, and 10 weeks, nitrate determinations were made. The results are given in figure 4.

It may be noted that during the first four weeks the alfalfa soil mixture accumulated more nitrates than did the sweet clover soil mixture, but after that time the sweet clover soil mixture passed it. The results are very similar to the top treatments in experiment 1. The straw depressed the nitrification process, although a tendency to rise is noted near the end of the experiment.

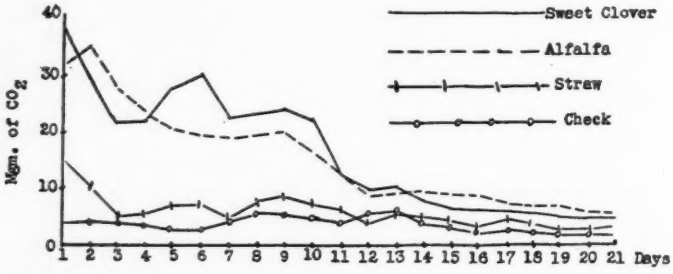


FIG. 5. AMOUNT OF CARBON DIOXIDE EVOLVED DAILY OVER A 21-DAY PERIOD FROM SOIL TREATED WITH 1 PER CENT QUANTITIES OF DIFFERENT KINDS OF ORGANIC MATTER

Carbon dioxide studies were also made of the alfalfa and the clover mixtures and of straw. The method used was the same as that described in experiment 2. The results are shown in figure 5.

No definite conclusions can be drawn from the relationship between the alfalfa and the clover mixtures. The differences noted are probably within the experimental error, and again raise the question whether the C-N ratio theory must not take into consideration the organisms working in the soil. It is probable that a longer period of test, or an experiment conducted after the Mucors had subsided in activity, would have shown different results. Certainly there is no question about the theory holding for the widely separated ratios of straw and of the two legumes.

CONCLUSIONS

These experiments consider the rate of nitrate formation and the rate of carbon dioxide evolution from soil receiving alfalfa roots and tops separately and combined, sweet clover tops and roots separately and combined, and wheat straw. The C-N ratio theory of decomposition appears to hold for these substances except for some factor which throws sweet clover out of its expected

place during the first few weeks. From the period when this discrepancy occurs, the author thinks that there are organisms, the Mucors in this case, which differ in activity according to the type of organic matter, and therefore disturb the results which would be obtained with a greater or lesser activity of these organisms. The organism present in large and vigorous colonies therefore must be considered in decomposition studies.

REFERENCES

(1) EMERSON, O. 1925 Soil Characteristics, p. 119. New York.
(2) HOLTZ, H. F., AND SINGLETON, H. P. 1925 Comparative value of alfalfa and sweet clover on soils in Lower Yakima Valley. *Jour. Amer. Soc. Agron.* 17: 326–333.
(3) MARTIN, T. L. 1925 Effect of straw on accumulation of nitrates and crop growth. *Soil Sci.* 20: 159–164.
(4) MARTIN, T. L. 1927 Decomposition studies of alfalfa and sweet clover roots and straw. *Soil Sci.* 24: 309–316.
(5) MARTIN, T. L. 1929 The effect of sweet clover and alfalfa roots and tops on the fungus flora of the soil. *Soil Sci.* 27: 399–405.
(6) MAYNARD, L. A. 1917 The decomposition of sweet clover as a green manure under greenhouse conditions. N. Y. (Cornell) Agr. Exp. Sta. Bul. 394.
(7) SIEVERS, F. J. 1922 Thirty-second annual report. Report of the division of soils. *Wash. Agr. Exp. Sta. Bul.* 175: 40–42.
(8) SIEVERS, F. J., AND HOLTZ, H. F. 1923 The influence of precipitation on soil composition and on soil organic matter maintenance. *Wash. Agr. Exp. Sta. Bul.* 176: 26–27.
(9) WAKSMAN, S. A. 1927 Principles of Soil Microbiology. Baltimore, Md.
(10) WAKSMAN, S. A., AND STARKEY, R. L. 1924 Microbiological analysis as an index of soil fertility: VII. Carbon dioxide evolution. *Soil Sci.* 17: 147.

EFFECT OF CROPPING WITH VARIOUS FERTILIZER, MANURE, AND LIME TREATMENTS UPON THE EXCHANGEABLE BASES OF PLOT SOILS

C. J. SCHOLLENBERGER AND F. R. DREIBELBIS[1]

Ohio Agricultural Experiment Station

Received for publication November 1, 1929

The fertility plots of the 5-year rotation at Wooster offer an exceptionally favorable opportunity for a study of the effect of cultivation with various fertilizers and lime treatment upon the exchangeable bases of the soil. These plots, started in 1893, are among the oldest in the United States. Although base-exchange studies on older plots at Rothamstead have been reported by Page and Williams (18), and at the Pennsylvania station by Merkle (17), in each case there has been a complication introduced by excessive lime content of the soil at the beginning of the experiment. In the case of the English work this was due to the former practice of chalking the land at very heavy rates, whereas the soil at the Pennsylvania experiment station is of residual limestone origin, in places very shallow. Naturally, where the limestone is very near the surface the soil will be saturated with bases and differ markedly from surface layers of deeper soil areas on the same or adjacent plots. Martin (16) at the California station has worked on soils cropped in cylinders since 1915, determining exchangeable bases in samples taken in 1926, as well as in samples of the soil as it was at the beginning. In this case, however, there was no fertilizer treatment, but a comparison between continuous cropping and fallowing systems. The soils, although in no case highly calcareous, are well supplied with bases and not acid. The Wooster silt loam, on which the plots about to be discussed are located, is a glacial drift soil derived from non-calcareous parent materials and is definitely acid in reaction and free from carbonates to a considerable depth.

THE PLOTS AND THEIR TREATMENT

As originally laid out, each of the 30 plots in a section of the 5-year rotation was one-tenth acre in area, with a 2-foot alleyway separating it from adjacent plots on each side; the dimensions of a plot were 16 by 272¼ feet. When the

[1] Assistants in agronomy. The authors wish to express their obligation to Mr. R. M. Salter, chief in agronomy, at whose instance this work was undertaken, for advice and encouragement. A part of the subject matter of this paper has been used by the junior author in a thesis presented to the graduate school at Ohio State University in partial fulfillment of the requirements for the degree of master of science.

lime treatment was begun in 1903, it was decided to lime only the west halves of plots in section D, and the east halves have never been limed. Since that date, records have been kept for the half plots, which are now considered as separate plots, 16 by 136⅛ feet or one-twentieth acre in area. The lime treatment of the west halves has been as follows:

		tons per acre
1903	Burned lime	0.90
1909	Ground limestone	1.00
1914	Ground limestone	4.08
1919	Ground limestone	1.70
1924	Ground limestone	1.80

The lime materials applied have contained a moderate amount of magnesia—about 10 per cent magnesium carbonate and 88 per cent calcium carbonate in the Kelly Island limestone applied in 1909 and 1914, and 8 per cent magnesium carbonate and 83 per cent calcium carbonate in the Ohio Penitentiary limestone since applied. At the time of sampling, the limed soil was found to contain carbonate equivalent to 1.33 tons $CaCO_3$ an acre, as the average of all plots.

The rotation, corn, oats, wheat, clover, and timothy, has been followed since the beginning, and with certain exceptions which will be noted, the original program has been followed. Every third plot has always been a check, without fertilizer treatment but limed and cropped exactly the same as the others on that end of the section. The fertilizer treatment of each plot is summarized in table 1.

Samples from certain of the lime-floats test plots are included in this work, since they are of interest in showing possible effect upon exchangeable bases of various lime materials applied at different rates. The plots of this corn, oats, and clover rotation begun in 1905 are one-twentieth acre in area. The samples were taken from section A. The plots considered have had manure with lime of different kinds and at several rates; the check plots have not been treated, but a plot with manure alone is available for comparisons. The record of the lime treatment of these plots is incomplete in that analyses of all the materials that have been applied are not available, nor were exactly the same materials always used.

For a fuller account of all these plots, with records of yields, the reader is referred to bulletin 381 (1) of the Ohio station.

THE SAMPLES AND THEIR PREPARATION

At the time the samples for the present work were taken (September 21–22, 1925), section D of the 5-year rotation had been fitted for wheat, but not fertilized or sown. Section A of the lime-floats test was in clover sod. The plots were sampled with a 1¼-inch auger to the depth of 6⅔ inches for surface samples. Thirty borings from each twentieth-acre plot were composited for each sample, and amounted to nearly a gallon of soil. According to the conclusions of Bear and McClure (4), this number of borings is more than ample

for a plot of this size. No very elaborate precautions were taken to have the sample borings spaced with mathematical accuracy, although care was taken

TABLE 1

Plan of fertilizing in 5-year rotation at Wooster

Plots one-tenth acre—Fertilizing materials in pounds to the acre

PLOT NUMBER	ON CORN			ON OATS			ON WHEAT			
	Acid phosphate	Muriate of potash	Nitrate of soda	Acid phosphate	Muriate of potash	Nitrate of soda	Acid phosphate	Muriate of potash	Dried blood	Nitrate of soda
1	...	...	...	...	...	...	...	...	...	...
2	80	...	...	80	...	...	160	...	...	...
3	...	80	...	...	80	...	...	100	...	...
4	...	...	...	...	...	...	...	...	...	...
5	...	...	160	...	...	160	...	...	50	120
6	80	...	160	80	...	160	160	...	50	120
7	...	...	...	...	...	...	...	...	...	...
8	80	80	...	80	80	...	160	100	...	...
9	...	80	160	...	80	160	...	100	50	120
10	...	...	...	...	...	...	...	...	...	...
11	80	80	160	80	80	160	160	100	50	120
12	80	80	240	80	80	240	160	100	50	200
13	...	...	...	...	...	...	...	...	...	...
14	80	80	160	...	...	...	160	100	50	120
15	...	...	...	...	...	...	160	100	50	120
16	...	...	...	...	...	...	...	...	...	...
17*	160	80	80	160	80	80	160	100	25	60
18	Barnyard manure, 8 tons each on corn and wheat									
19	...	...	...	...	...	...	...	...	...	...
20	Barnyard manure, 4 tons each on corn and wheat									
21	Same elements as 17, but nitrogen in oilmeal									
22	...	...	...	...	...	...	...	...	...	...
23	Same elements as 17, but nitrogen in dried blood									
24	Same elements as 17, but nitrogen in sulfate of ammonia									
25	...	...	...	...	...	...	...	...	...	...
26	Same elements as 11, but phosphorus in bonemeal									
27	Same elements as 17, but nitrogen in nitrate of lime and cyanamid									
28	...	...	...	...	...	...	...	...	...	...
29	Same elements as 11, but phosphorus in basic slag									
30	Same elements as 17, but nitrogen in tankage									

* During the first 5 years, quantities of elements on plots 17, 21, 23, and 24 same as 11; nitrogen and potassium on 30 smaller. Previous to 1910, plot 27 same as 11, with nitrogen in nitrate of soda, phosphorus in dissolved boneblack. Treatment on plots 12, 21, and 23 changed in spring of 1921 to 320 pounds of acid phosphate on each grain crop; nitrate of soda for oilmeal and dried blood on 21 and 23; muriate of potash reduced one-half on 23; treatment on 30 discontinued. Since 1924, cyanamid has been substituted for nitrate of lime on plot 27.

to have them distributed over the plot as well as could be done by pacing distances and estimating with the eye. No boring was taken within less than

two feet of the edge of a plot. The soil was in good condition for sampling with an auger, and was collected in one-gallon friction-top tin pails. It was immediately spread on paper to dry in a clean and airy place, and as soon as air-dried was replaced in the pail and covered. The dried soils were afterwards crushed between rubber rolls and sifted through a 2-mm. round-hole sieve. The sifted, fine earth was mixed by being passed several times through a coarse screen and finally stored in the pail in which it had been collected, until such time as the analytical work could be started.

Concerning the manner of the original sampling of soil from the plots, done in 1894, little is known. A spade was probably used as the tool. Unfortunately, only a few plots were represented by old samples, and this phase of the subject is least satisfactory.

METHODS EMPLOYED

Only the barest outline of analytical procedures is given here, as they will be described in detail in a separate paper. The weight of sample taken was in all cases 100 gm. air-dry soil, packed in a special percolator tube with arrangements for protecting the solution from the atmosphere. For leaching, 750 cc. *N* ammonium acetate solution as pH 7.07 was employed. The advantages of this solution have been noted previously (7, 19) and the quantity named has been shown by preliminary experiments to be ample for removing all exchangeable bases from 100 gm. Wooster silt loam sieved through 2-mm. mesh. Exchangeable hydrogen was determined by a procedure of electrometric titration of the entire quantity of leachate, and the other exchanged cations were separated and determined in the solution after evaporation and treatment to expel the ammonium salt. Exchangeable ammonium was determined in a separate sample extracted with 0.1 *N* HCl and the ammonia distilled into standard acid. Ammonium absorbed by the leached soil and by the soil washed in 80 per cent alcohol was determined, by a procedure similar to that of Kelly and Brown (12), on a quarter weight of the sample, still damp with alcohol. In the case of limed soils, the remainder of the leached sample was dried and ground for determination of carbonate and for comparison with similar data obtained from the unleached soil, thus correcting for carbonate dissolved during leaching. Blank determinations for correction of errors from impurities in reagents or from other causes were run whenever necessary. Determination of the pH values of 1 : 1 water suspensions of the fresh samples were made by the quinhydrone electrode method of L. D. Baver, who has described his procedure (3, 4).

INTERPRETATION OF DATA

Analytical work is never absolutely accurate, nor would the soil chemist be in a much more favorable position to make decisions even if his methods were perfect. The material on which he works is far from being uniform in composi-

tion, varying from plot to plot and from place to place on even the smallest plot. Variations on the plot are overcome by taking a sufficient number of borings from separate places to ensure a composite sample representative of the plot as a whole, but for variability of the plots themselves one is obliged to resort to mathematical methods for correction. If a number of determinations of some constituent are run on the same sample, we have presumably a uniform sample on which to work and the theory of probability applies to the results. If the soil over the section is assumed to have been uniform at the start and to have been affected uniformly by any accidental factors since operative, for example, erosion or drift of limestone dust from a roadway, then a formula such as Bessel's for probable error of the mean might be applied. The magnitude of such probable error indicates how well the mean represents all the results, and how much significance may be credited to a difference between means. The calculations have been made for averaged data from check plots only, and will be found in tables 2 to 4. A method of calculation very simple in principle has long been in use by Thorne (21) for compensation of variations between these plots in calculating increases in crop yields due to treatment. The soil is assumed to vary in productivity (or composition) in a uniform, progressive manner. Since every third plot is a check, without special treatment, one may judge the direction of this variation for every plot, and calculate the figure the treated plot might have shown, had it been treated in the same way as the check. One-third of the difference between the checks is added to the adjacent check if the figures are increasing, or subtracted if diminishing, in order to get the hypothetical figure the treated plot might have shown had it not been treated. The difference between this calculated figure and that actually found represents the net effect of the treatment. This simple method appears to be the best available for most of the comparisons in the present work. It should be remembered, however, that in many cases there is no proper measure of the reliability of data, so that the importance of differences indicated cannot be judged. To do this, it would be necessary to make several duplicate samplings and carry out a number of determinations on each, so that numerous values could be averaged and the probable error of the mean calculated. Some of the comparisons in the present work involve numerous paired data, for the study of which Love's (13) modification of the "Student" method is especially adapted. This will be applied whenever possible.

Data for unlimed plots of section D, 5-year rotation represent the earlier work, which was always repeated and the averages of closely agreeing duplicates which were tabulated. Later, the analysts had more confidence and the work was not duplicated unless a known mishap had occurred.

RESULTS

Effect of 31 years' cropping

A few samples taken from the plots of section D, 5-year rotation, in 1894, at the time this fertility experiment was started, were available for analysis; the

TABLE 2

Exchangeable bases in original soil compared with check plots of section D, 5-year rotation

Expressed as milligram-equivalents per 100 gm. air-dry soil

PLOT NUMBER	EXCHANGEABLE BASES								
	H	Al	Mn	Ca	Mg	K	Na	Total	NH_4 absorbed
10	Lost	0.18	0.74	2.73	0.67	0.22	0.38	Lost	8.49
11	5.28	0.24	0.86	2.03	0.59	0.21	0.36	9.33	8.00
16	4.00	0.17	0.94	3.62	0.55	0.18	0.30	9.59	8.35
19	4.60	0.18	0.97	2.44	0.74	0.22	0.39	9.36	8.70
20	4.52	0.26	0.94	2.36	0.58	0.19	0.31	8.90	7.78
1894—Average	4.60±0.18	0.21±0.01	0.89±0.02	2.64±0.18	0.62±0.02	0.21±0.01	0.34±0.01	9.29±0.10	8.26±0.11
1925—Average Checks Unlimed	6.11±0.12	0.28±0.02	0.27±0.01	1.23±0.09	0.24±0.02	0.10±0.00	0.04±0.01	8.08±0.05	7.60±0.11
1925—Average Checks Limed	0.29±0.06	.....	0.04±0.00	8.08±0.21	1.37±0.03	0.09±0.00	0.02±0.01	*8.15±0.12	8.85±0.13

* Corrected for carbonates dissolved from soil.

results obtained from the examination of five of these samples are presented in table 2, together with averages of data obtained from 10 unlimed and 10 limed check plots sampled in 1925 for comparison. The probable errors of the means calculated by Bessel's formula are included to facilitate comparisons between the averaged figures, although the number (five) of old samples scarcely justifies the application of the statistical method.

The principal exchangeable cation, *hydrogen*, has increased by 1.51 ±0.22 m.e., a significant amount, but the increase in average *aluminum*, 0.07 ±0.02 is scarcely significant. *Manganese* has decreased by 0.62 ±0.02 m.e., *calcium* by 1.41 ±0.20 m.e., *magnesium* by 0.38 ±0.03 m.e., *potassium* by 0.11 ±0.01 m.e., and *sodium* by 0.30 ±0.01 m.e. per 100 gm. All these differences are significant, and indicate important losses of the soil's essential cations as the result of cropping. *Total bases* have decreased by 1.21 ±0.11 and ammonium absorbed by 0.66 ±0.15 m.e.

To summarize the effect of 31 years' cropping without fertilizer or lime treatment upon the exchangeable base content of the Wooster silt loam, it may be said that the cations, manganese, calcium, magnesium, potassium, and sodium have decreased, whereas hydrogen has increased. In spite of the considerable increase in hydrogen, there has been a net decrease of total bases extracted from the soil and of exchange capacity, as indicated by their replacement by ammonium ion after the leaching process.

Although it would be possible to spend much time in a discussion of differences between these old samples and those recently taken, it does not seem advisable to do so, for the reason that the losses in desirable cations and the increases in undesirable cations indicated cannot be attributed solely to removal in crops or to leaching, but are undoubtedly in part due to erosion. On certain parts of this section, especially on the higher east end (unlimed side) it is evident that the present surface soil is very different from what it was 30 years ago. In spots, the light brown silt loam designated as the A_3 horizon (8 to 14 inches) in descriptions of the virgin soil profile is now the surface soil.

Effect of fertilizer treatment upon unlimed soil

Data for exchangeable bases in the soil of every plot of section D, 5-year rotation fertility experiment are presented in table 3, for the unlimed ends, and in table 4 for the limed ends of the plots. Data for the unlimed ends in table 3 will be discussed first.

Hydrogen in the exchangeable form is lowest on plot 1, which is likewise highest in exchangeable calcium, and has the highest pH value among the check plots. This plot adjoins a roadway surfaced with crushed limestone, and considerable dust raised by traffic settles upon the plot. Although this plot is recognized as abnormal, data from it have not been excluded from averages. The plot highest in exchangeable hydrogen is that receiving complete fertilizer with ammonium sulfate as the source of nitrogen, and this is also the most acid plot and is lowest in exchangeable calcium among fertilized plots. A study of

TABLE 3

Exchangeable bases in soil from unlimed plots of section D, 5-year rotation

Expressed as milligram-equivalents per 100 gm. air-dry soil

PLOT NUMBER	TREATMENT PER ACRE PER ROTATION			EXCHANGEABLE BASES										pH
	S.P.	KCl	$NaNO_3$	H	Al	Mn	Ca	Mg	K	Na	NH_4	Total	NH_4 absorbed	
	pounds	*pounds*	*pounds*											
1	Check			4.86	0.24	0.24	2.20	0.40	0.09	0.00	0.07	7.86	8.54	4.94
2	320	...	...	5.74	0.27	0.24	2.00	0.30	0.12	0.00	0.18	8.58	8.40	4.83
3	...	260	...	5.70	0.29	0.28	1.63	0.37	0.27	0.06	0.16	8.47	8.10	4.75
4	Check			6.00	0.42	0.33	1.34	0.30	0.11	0.02	0.15	8.25	8.38	4.75
5	...	...	440	5.90	0.26	0.30	1.37	0.31	0.10	0.10	0.14	8.22	8.18	4.76
6	320	...	440	5.60	0.27	0.25	1.61	0.27	0.09	0.13	0.12	8.07	8.23	4.90
7	Check			5.80	0.46	0.26	1.27	0.33	0.10	0.00	0.05	7.81	7.80	4.70
8	320	260	...	5.66	0.24	0.27	1.61	0.25	0.24	0.01	0.12	8.16	8.04	4.81
9	...	260	440	5.48	0.26	0.29	1.45	0.35	0.33	0.31	0.15	8.36	7.85	4.70
10	Check			5.70	0.29	0.23	1.37	0.33	0.10	0.00	0.12	7.85	7.77	4.79
11	320	260	440	5.80	0.32	0.27	1.32	0.26	0.25	0.12	0.17	8.19	8.00	4.74
12	320	260	680	5.86	0.23	0.28	1.45	0.22	0.22	0.20	0.20	8.43	7.93	4.85
13	Check			6.47	0.19	0.29	0.69	0.15	0.09	0.06	0.11	7.86	7.30	4.58
14	240	180	280	6.90	0.15	0.27	1.09	0.17	0.15	0.13	0.10	8.81	7.52	4.74
15	160	100	120	6.65	0.22	0.29	1.16	0.22	0.20	0.17	0.11	8.80	7.55	4.65
16	Check			6.70	0.28	0.30	0.83	0.17	0.10	0.06	0.09	8.25	7.13	4.64
17	480	260	220	6.28	0.10	0.24	1.34	0.22	0.16	0.13	0.10	8.47	8.23	4.82
18	Manure, 16 tons			6.18	0.11	0.37	1.46	0.51	0.21	0.11	0.14	8.98	8.48	4.92
19	Check			6.47	0.22	0.29	1.21	0.22	0.11	0.11	0.10	8.51	7.46	4.84
20	Manure, 8 tons			6.58	0.10	0.32	1.46	0.40	0.14	0.05	0.11	9.06	8.03	4.86
21*	480	260	Oil meal	6.60	0.11	0.26	1.63	0.23	0.20	0.19	0.12	9.23	7.78	4.77
22	Check			6.50	0.23	0.25	1.17	0.21	0.09	0.12	0.08	8.42	7.13	4.88
23	480	260	Dried blood	6.88	0.17	0.27	1.36	0.20	0.18	0.10	0.09	9.08	7.12	4.73
24	480	260	$(NH_4)_2SO_4$	6.91	0.30	0.35	0.77	0.14	0.21	0.05	0.19	8.62	7.09	4.47

25	Check			6.13	0.20	0.25	1.25	0.25	0.09	0.05	0.08	8.10	7.20	4.77
26	Bone	260	440	6.03	0.08	0.26	1.48	0.26	0.20	0.18	0.15	8.56	7.79	4.97
27	480	260	Nitrate of lime	6.11	0.12	0.25	1.76	0.21	0.24	0.01	0.13	8.71	7.21	4.83
28	Check			6.50	0.28	0.27	0.95	0.20	0.08	0.00	0.09	8.09	7.30	4.67
29	Slag	260	440	5.99	0.06	0.26	2.02	0.31	0.22	0.13	0.10	9.03	8.12	4.93
30	480	260	Tankage	6.28	0.07	0.19	1.34	0.22	0.12	0.00	0.10	8.25	7.89	4.93
Average unlimed checks.....				6.11±0.12	0.28±0.02	0.27±0.01	1.23±0.09	0.24±0.02	0.10±0.00	0.04±0.01	0.09±0.01	8.08±0.05	7.60±0.11	

* Plots 21, 23, 24, 27, and 30 receive the same amounts of the fertilizer elements as plot 17, but the source of nitrogen is oilmeal, dried blood, sulfate of ammonia, nitrate of lime plus cyanamid, and tankage, respectively, instead of nitrate of soda. Plot 30 has not been fertilized since 1919. Similarly, plots 26 and 29 receive the same fertilizers as plot 11, except that the source of phosphoric acid is bonemeal and basic slag respectively, instead of superphosphate.

the data for exchangeable hydrogen by Thorne's method of calculating the effect of treatment indicates that superphosphate alone increases hydrogen considerably, but this conclusion depends upon a comparison with plot 1, which does not inspire much confidence. Muriate of potash has the same effect, but nitrate of soda causes a decrease; in both these cases the effect is slight. Of the 10 plots receiving nitrate of soda, only 1 indicates appreciable increase in exchangeable hydrogen, whereas 8 indicate decreases. On plots receiving complete fertilizers with other ammoniates, only nitrate of lime (one preceding application substituted by cyanamid) has caused a decrease; oil meal, dried blood, and sulfate of ammonia caused increases in exchangeable hydrogen. The effect of the sulfate has been especially marked. Comparisons of pH values of the samples lead, in a large majority of cases, to the same conclusions as to the effect of the fertilizer ingredients as are indicated by the titrations of exchangeable hydrogen.

Aluminum indicated to be exchangeable, by neutral ammonium acetate leaching, is quite frequently at variance with what would be expected from the exchangeable hydrogen and pH values of these samples. The actual quantity of aluminum obtained in solution is so small, however, that no great importance can be attached to it. Aluminum is nearly always less in samples from fertilized plots than in the adjacent checks, but plot 24 receiving ammonium sulfate is a notable exception. The basic fertilizers applied to plots 26, 27, and 29 appear to have been very effective in reducing aluminum solubility.

Manganese figures are noticeably uniform and furnish no consistent indications of any very marked influence by fertilizers. Plots receiving manure are notably high, and plot 24, which is the most acid plot, is also highest among fertilized plots in exchangeable manganese content.

Manganese is included among the elements essential to plant growth, although it has been shown by Funchess (9) that excessive amounts of water-soluble manganese may be responsible for the toxicity following the long-continued use of dried blood or sulfate of ammonia on acid soils. A chlorosis attributed to lack of available manganese is sometimes seen, and may be caused by liming, according to Hartwell and Crandall (10). Manganese is unique among the exchangeable cations in that it may be considered as a labile base, passing from the active exchangeable form into a neutral higher oxide or vice versa according to conditions prevailing at a particular time. It has been shown (20) that the higher oxides of manganese are readily reduced when the soil is exposed to anaerobic conditions otherwise favorable to bacterial activity. The bivalent manganese is an active exchangeable base (14), and has been proved to have the same effect in increasing the pH value of the soil that an equivalent amount of exchangeable Ca would have (20). Addition of organic matter, as manure, is favorable to reduction of the soil's abundant supply of higher oxides of Mn, and it may be supposed that roots and other crop residues turned under would have a similar effect. It is possible that the oxidation-reduction equilibrium depends upon the reaction of the soil also,

and the more acid the soil, the greater reducing effect may be due to organic matter. This might explain the high exchangeable Mn on the very acid plot 24. As will appear later, liming reduces exchangeable Mn to a low figure.

Exchangeable *calcium* may be expected to be affected by fertilizer treatment, because most fertilizers contain calcium. Superphosphate offers a neutral salt, calcium sulfate, as well as acid phosphates, whereas basic slag, bone, and cyanamid carry alkaline calcium compounds. The unfertilized check plot 1 is highest in exchangeable calcium, because of dust from a limestone macadamized roadway adjacent. Calculation indicates that plot 2 might contain 1.91 m.e., had it not been fertilized. As 2.00 m.e. was found, it is indicated that superphosphate alone has caused a net increase of 0.09 m.e. Ca. The calculated content of plot 3 is the same as that actually found, indicating that muriate of potash has been without effect upon exchangeable calcium, but nitrate of soda alone has effected an insignificant conservation, 0.02 m.e., in plot 5. With superphosphate on plot 6, the nitrate is responsible for a large net gain in exchangeable calcium, 0.28 m.e. or three times that shown by the superphosphate alone. Plot 8 shows another considerable gain, 0.31 m.e., attributable to superphosphate. On plot 9, receiving muriate of potash and nitrate of soda only, the indicated gain of 0.12 m.e. must be attributed to the nitrate. Plot 11 is the first plot with complete fertilizer, superphosphate, muriate, and nitrate, and shows a net gain of 0.18 m.e. Ca. Plot 12 received the same treatment except that 50 per cent more nitrate is applied, and the net gain in calcium is 0.54 m.e. Plots 14 and 15 receive smaller applications of complete fertilizers, but show considerable net gains in exchangeable calcium, 0.35 and 0.37 m.e. respectively. Plot 17 receives more superphosphate and less nitrate than most of those considered, but shows a not gain of 0.38 m.e. calcium. Manure, 16 tons on plot 18 and 8 tons on plot 20, causes net gains of 0.37 and 0.26 m.e. Ca respectively. Plots 17, 21, 23, 24, and 27 are fertilized alike except with respect to source of nitrogen. The oil meal on plot 21 appears to be slightly more favorable to the conservation of calcium than does nitrate of soda on plot 17, the figures being 0.44 and 0.38 m.e. respectively. Dried blood on plot 23 is less favorable, however, showing only 0.16 m.e gain, whereas the sulfate of ammonia on plot 24 has caused a loss of 0.46 m.e., the only instance in which a loss of calcium was shown by a plot receiving complete fertilizer. Bonemeal and cyanamid with nitrate of lime, applied to plots 26 and 27, have caused increases of 0.33 and 0.71 m.e. calcium, respectively. An exact figure for the increase in exchangeable calcium due to the application of basic slag to plot 29 cannot be calculated, but evidently it is large.

Magnesium is not affected to any great extent nor in a consistent manner by applications of fertilizers, but manure has caused large increases on plots 18 and 20. Sulfate of ammonia has caused an important decrease in exchangeable magnesium on plot 24.

Potassium is of especial interest as an exchangeable base because deficiency in this element is frequently a factor limiting crop production. Martin (16)

and Fraps (8) have presented much evidence indicating that the exchangeable potassium of the soil is reduced by cropping. Exchangeable potassium in these unlimed check plots varies from 0.08 to 0.11, with a mean of 0.10 ±0.00 m.e. to the 100 gm. Where potash fertilizers have not been applied, the figures do not differ significantly from this. This is a very small amount, equivalent to only 78 pounds potassium to the acre, in the topsoil. Average yields for these unlimed check plots for the rotation preceding the sampling were about 16.2 bushels of corn with 950 pounds of stover, 22.7 bushels of oats with 948 pounds of straw, 7.2 bushels of wheat with 737 pounds of straw, 893 pounds of clover hay, mostly weeds, and 1825 pounds of timothy hay.

Assuming average composition for all these crops, the total potassium removal for one rotation is in the neighborhood of 60 pounds. It is evident that crops on these plots obtain their potassium from some source in addition to the exchangeable potassium of the surface soil, undoubtedly in part from the subsoil. The effect of potassium in fertilizers in raising the exchangeable potassium of the soil is very plainly shown. The highest figures are found in the cases of plots 3 and 9, receiving potash but no phosphorus, which is really the limiting element. Under these circumstances the crops have been small, allowing a part of the applied potassium to accumulate. Manure at the rate of 16 tons to each rotation is sufficient to maintain the exchangeable potassium at a fairly high level, but 8 tons a rotation does not. Fertilization of plot 30 on all the sections was discontinued in 1921, hence the last application of fertilizer to plot 30 in this section was for corn in 1919. In the six years that had elapsed before the samples were taken, exchangeable potassium on plot 30 had fallen to practically the same figure as that shown by check plots. Page and Williams (18) conclude from data obtained from analyses of samples from plots at Rothamstead, and of the crops grown thereon, that potash applied as the sulfate is not completely accounted for by increases in exchangeable potassium in the upper 18 inches of soil, nor is it removed in the drainage; they further conclude from this, that there is considerable fixation of potassium in non-exchangeable form, or a change from the exchangeable to the non-exchangeable states. The data obtained from section D, 5-year rotation are not sufficiently complete to justify a similar conclusion, as only a few crops have been analyzed, and there are no analyses of drainage water or of the subsoil on the plots. Assuming average potash contents for crops, however, a similar calculation using data from the present investigation may be worth while.

Crop increases due to fertilization are given in bulletin 381 (1) and the potash contents of crops are assumed to be averages of numerous unpublished analyses made at this station, from which it appears that approximately 53 pounds of potassium are contained in the average crop increases to be attributed to fertilization during each rotation. The average application of potassium to the potash-fertilized plots is very nearly 100 pounds a rotation, leaving about 47 pounds of potassium in the soil to each rotation, or 282 pounds since the experiment started. The average fertilized and unlimed plot contains 0.19 m.e.

potassium, and the average check plot 0.10 m.e.; the difference, 0.09 m.e., is equivalent to 70 pounds an acre, from which it appears that of the potassium applied and not utilized by crops, only one quarter is retained in the surface soil in exchangeable form. Erosion is undoubtedly responsible for some of the loss, however, and the data furnish no definite proof that potassium is fixed in non-exchangeable form.

Sodium has not accumulated to any great extent in the soil, although heavy applications of the nitrate have been made to some plots, and available analyses of crops do not indicate that much would have been removed in them. There is very little exchangeable sodium in the soil of check plots, in many cases the figures being no greater than the blank determination. Where sodium has been applied in fertilizers the figures are generally higher than the adjacent checks, but show no great degree of consistency among themselves, therefore, extended discussion does not seem warranted.

Ammonium in the exchangeable form has been shown by Joffe and McLean (11) to be a very available source of nitrogen and would be expected to be utilized rapidly and almost completely in soils adapted to crop growth, hence it was not thought necesary to determine it as an exchangeable base originally in the soil. After the appearance of Merkle's paper (17) in which is reported a considerable accumulation of ammonium in the soil of a plot heavily fertilized with sulfate of ammonia, it was decided to make the determinations, and the results obtained on these air-dry samples after over three years' storage are presented in the tables. The quantities found are not large, nor is there much consistency about them, except that plot 24 shows the highest figure, 0.19 m.e., as would be expected from its treatment. Because it was thought that part of the ammonia might have escaped during drying, as is known to happen when soils saturated with ammonia are dried, or some may have been absorbed from the laboratory atmosphere, because of possible imperfect sealing of the container, new samples were taken from two plots, 24 and 25 unlimed, and determinations were run on the fresh samples the same day (June 24, 1929). The check, plot 25, contained 0.08 m.e. ammonia in the fresh soil, the same figure as shown by the dried sample, both being on the dry-soil basis. Plot 24 showed less ammonia, 0.13 m.e., in this fresh sample, than had been contained in the dried sample. The difference, 0.05 m.e., represents net gain in ammonia and is equivalent to 14 pounds of nitrogen to the acre. About a fortnight before the last sampling, plot 24 had been fertilized for corn, complete fertilizer containing 13 pounds of nitrogen in sulfate of ammonia being broadcast. It is evident that there is practically no tendency for the ammonium ion applied as sulfate to accumulate in the soil under conditions prevailing at Wooster.

Effect of fertilizer treatment upon limed soil

Data on exchangeable bases contained in samples from the limed ends of the plots are presented in table 4. The influence of the lime treatment upon some

TABLE 4

Exchangeable bases in soil from limed plots of Section V, 5-year rotation

Expressed as milligram-equivalents per 100 gm. air-dry soil

PLOT NUMBER	TREATMENT PER ACRE PER ROTATION			EXCHANGEABLE BASES										pH
	S.P.	KCl	$NaNO_3$	H	Mn	Ca	Mg	K	Na	NH_4	Carbonates*	Total†	NH_4 absorbed	
	pounds	*pounds*	*pounds*											
1	Check			alk.	0.03	10.70	1.23	0.11	0.02	0.11	3.80	8.40	9.62	7.81
2	320	...	...	0.50	0.05	8.20	1.40	0.10	0.00	0.14	2.14	8.25	9.88	7.50
3	...	260	...	0.50	0.04	8.11	1.54	0.24	0.03	0.13	2.24	8.35	9.92	7.45
4	Check			0.50	0.04	7.98	1.57	0.09	0.00	0.13	1.33	8.98	9.62	7.45
5	...	...	440	0.20	0.03	8.04	1.56	0.08	0.13	0.13	2.27	7.90	9.56	7.56
6	320	...	440	0.60	0.04	7.79	1.27	0.07	0.14	0.11	1.92	8.10	9.32	7.43
7	Check			0.56	0.05	7.52	1.33	0.07	0.01	0.11	1.80	7.85	8.52	7.39
8	320	260	...	0.48	0.05	7.72	1.20	0.16	0.07	0.13	2.24	7.57	9.24	7.33
9	...	260	440	0.14	0.04	7.68	1.29	0.20	0.17	0.16	2.24	7.44	9.14	7.52
10	Check			0.06	0.04	7.88	1.32	0.10	0.00	0.11	1.50	8.01	8.70	7.60
11	320	260	440	0.20	0.07	8.35	1.25	0.14	0.15	0.10	1.86	8.40	9.44	7.54
12	320	260	680	0.30	0.04	8.65	1.31	0.14	0.15	0.13	2.26	8.46	9.90	7.64
13	Check			0.60	0.04	8.06	1.35	0.09	0.03	0.08	1.33	8.92	9.55	7.41
14	240	180	280	0.60	0.04	7.70	1.27	0.10	0.06	0.07	1.25	8.59	8.82	7.37
15	160	100	120	0.30	0.04	7.68	1.33	0.11	0.03	0.10	1.61	7.98	8.51	7.35
16	Check			0.31	0.03	7.79	1.33	0.08	0.13	0.15	2.39	7.43	8.30	7.60
17	480	260	220	0.50	0.04	8.18	1.33	0.15	0.06	0.13	0.81	9.58	9.37	7.55
18	Manure, 16 tons			0.50	0.06	8.12	1.50	0.17	0.03	0.11	1.65	8.84	9.82	7.55
19	Check			0.50	0.04	7.40	1.57	0.10	0.00	0.13	1.35	8.39	9.58	7.41
20	Manure, 8 tons			0.30	0.05	8.54	1.64	0.14	0.02	0.07	1.60	9.16	9.90	7.60
21	480	260	Oil meal	alk.	0.06	8.48	1.38	0.12	0.06	0.07	1.70	8.47	9.02	7.51
22	Check			alk.	0.04	8.18	1.42	0.09	0.00	0.07	2.10	7.70	8.60	7.63
23	480	260	Dried blood	0.00	0.07	8.00	1.17	0.13	0.07	0.08	2.27	7.25	8.98	7.32
24	480	260	$(NH_4)_2SO_4$	0.20	0.07	7.64	1.16	0.14	0.00	0.09	1.72	7.58	9.10	7.16

25	Check			alk.	0.05	8.02	1.38	0.08	0.00	0.08	1.18	8.43	8.62	7.59
26	Bone	260	440	0.36	0.05	7.38	1.19	0.17	0.13	0.07	1.50	7.85	8.90	7.50
27	480	260	Nitrate of lime	0.20	0.04	7.84	1.14	0.14	0.00	0.09	2.37	7.08	8.50	7.42
28	Check			0.40	0.04	7.08	1.19	0.08	0.00	0.05	1.48	7.36	7.86	7.42
29	Slag	260	440	0.00	0.04	7.86	1.14	0.13	0.14	0.07	1.55	7.83	8.54	7.68
30	480	260	Tankage	0.30	0.03	8.42	1.25	0.11	0.00	0.08	2.59	7.60	8.98	7.55
Average limed checks.....				0.29±0.06	0.04±0.00	8.08±0.21	1.37±0.03	0.09±0.00	0.02±0.01	0.10±0.01	1.83±0.16	8.15±0.12	8.85±0.13	

* Carbonate dissolved from soil during leaching process by difference between carbon dioxide content of unleached and leached soil.

† Corrected figure for exchangeable bases, obtained by deducting the equivalent of dissolved carbonate from the total bases in leachings.

elements is so great that any possible effects of fertilizers are masked. The discussion, therefore, will be brief.

Exchangeable hydrogen is reduced to a low figure by the heavy liming, and the leachings from some samples are more alkaline than the original solution, indicating no exchangeable hydrogen. These samples, with only one exception, were higher in carbonates and showed more solution of the latter during leaching, than most of the other samples.

Aluminum is reduced to a mere trace, so small that the figures have no significance and are not tabulated. Manganese is greatly reduced, and calcium and magnesium are much increased. The addition of fertilizer potash to the limed soil is reflected by the exchangeable potassium in the same manner as already noted for the unlimed soil. The average potassium content of limed fertilized plots is 0.14 m.e., indicating that liming does not favor the accumulation of potassium, probably because the larger crops remove the potassium. Exchangeable sodium is affected by nitrate of soda in fertilizer mixtures in much the same way as on the unlimed soil, and exchangeable ammonium is of no more significance in the case of the limed plots than in those unlimed.

Effect of lime upon exchangeable bases

The data obtained from analyses of samples from section D serve not only to show possible effects of fertilizers upon the exchangeable bases of the soil, but also afford an excellent opportunity for observation of the effect of lime upon exchangeable bases. Samples from limed and unlimed ends of all plots were examined, therefore the data are naturally paired and Student's method for calculating odds that differences between averages are significant may be applied. The effects of lime treatment in reducing exchangeable hydrogen, aluminum, and manganese, and in increasing calcium and magnesium are so plainly shown that it will not be necessary to discuss them mathematically. It is only when the data do not obviously point to a conclusion that statistical treatment is necessary.

According to data in bulletin 381 (1) limestone used on the 5-year rotation returned an average gain of $7.84 an acre over cost of treatment for the rotation preceding that in which the samples were taken. The increased crop represented by this profit undoubtedly made a heavier draft upon the soil's available potassium, so that the average exchangeable potassium of all limed plots would be expected to be lower than that of unlimed plots. These averages are 0.12 and 0.16 m.e., to the 100 gm. respectively, and calculation by Student's method indicates practically infinite odds that the difference, 0.04 m.e., assumed to represent increased removal of potassium in crops, may not have been so great from chance alone. The lime treatment has probably increased the removal of exchangeable potassium from the soil.

The average exchangeable sodium of all unlimed plots is 0.09 m.e. and of limed plots 0.06 m.e. to 100 gm. The odds are only 50 to 1 that the increased removal, 0.03 m.e., indicated to be due to liming, may not be so great from chance alone.

Exchangeable ammonium might be expected to be lower in limed soil, increase in nitrification being a well-known effect of liming an acid soil. As averages of all plots, the exchangeable ammonium figures are 0.12 m.e. for unlimed and 0.10 m.e. for limed soils. The odds are 77 to 1 that the small decrease of 0.02 m.e. or 6 pounds nitrogen an acre may not have been so great by chance. Liming has probably had some effect upon exchangeable sodium and ammonium but the actual quantities involved are so small that this cannot be important.

An entirely unexpected apparent effect of lime treatment is the reversal of the relation between exchangeable bases removed from the soil by the leaching process and ammonium ion absorbed by the soil from the solution. According to the theory of cation exchange between soil and solution, these should be equivalent; practically, the dissolved bases (including hydrogen) would be expected to be in excess, as most soils probably contain some cations easily soluble but not a part of the exchange complex. In the case of the limed soils, the amounts of undecomposed carbonate can be determined before and after the leaching process, and a correction for dissolved carbonate so made. This was done, but does not entirely solve the difficulty due to the solution of carbonates. When the limestone is dissolved, its carbon dioxide is supposed to remain in solution and conduct itself as an acid. Some may be lost, however, lowering the apparent exchangeable hydrogen content and so causing the total of bases found and corrected for carbonates dissolved to be less than the ammonium exchanged. Another source of difficulty arises from the presence of dissolved calcium and magnesium from limestone continuously going into solution during the leaching process. As the solution already contains an appreciable concentration of these elements, the same ions can never be completely displaced from the soil. This would cause low values for calcium and magnesium exchanged, but ammonia absorbed should also be less by the equivalent amount. Several experiments in which ground limesone alone was leached with the neutral ammonium acetate indicated that the calcium and magnesium are taken into solution in practically the same ratio in which they exist in the stone, therefore both will be affected.

As the average of all plots on the unlimed side of section D, total bases extracted average 8.44 m.e., and on the limed side the corrected average is 8.13 m.e. Odds are 77 to 1 that a difference as large as 0.31 m.e. would not occur as a result of chance, from which it appears fairly certain that the lime treatment has had the apparent effect of reducing exchangeable bases extracted. This depression in extraction may affect calcium and magnesium only and be caused by the presence of these ions in the leaching solution, derived from residual limestone. Ammonium absorbed averages 7.79 m.e. on the unlimed plots and 9.13 m.e. on those limed. Odds are infinite that the difference of 1.34 m.e. would not result from chance, and it seems certain that the liming is responsible for the excess of ammonium absorbed over bases exchanged. It was at first thought that the presence of limestone during leaching might

increase ammonium absorption by lowering the H-ion concentration and so promoting exchange of ammonia for hydrogen, an instance of dependence of absorptive capacity upon pH, as discussed by Bradfield (5). Several trials in which 2.5 per cent precipitated calcium carbonate was added to soil from the unlimed end of plot 24 and in which the mixtures were leached with neutral ammonium acetate showed that the ammonium absorption was decreased by 0.30 m.e. as a result of the addition of calcium carbonate. Evidently, this is due to incomplete saturation of the absorptive capacity of the soil by ammonia, the calcium ions in the leaching solution being absorbed to some extent also. To overcome this it would be necessary to continue leaching until the last traces of calcium carbonate had been removed. Some other experimental work indicated that the apparent deficiency in ammonia absorbed shown by the unlimed soil was not due to the high acidity of the soil. A sample of the unlimed soil was leached with 0.1 *N* HCl and washed with water to replace all bases with hydrogen. The reaction of this hydrogen-saturated soil was pH 3.6. Samples of this very acid soil and of the original soil were leached with neutral ammonium acetate at the same time, and determinations of ammonium absorbed showed that the previous acid extraction had caused an increase of 0.60 m.e. over the figure of 8.05 m.e. for the sample not acid-extracted, but otherwise treated the same. From these results it appears that the reaction of the soil is not in itself an important factor in determining exchange capacity, at least not under the conditions prevailing during a neutral ammonium acetate leaching, which insures relative constancy of the reaction of the solution in contact with the soil. It must be concluded that liming in some way increases the absorption of ammonium from this leaching solution, and from a consideration of the forgoing evidence it appears probable that this increase is the result of an actual building up of base exchange capacity, the effect of the long-continued action of lime upon soil constituents.

Breazeale and Magistad (6) have noted that treatment of finely powdered orthoclase with a solution of a calcium salt at pH 8 has resulted in increasing the exchange properties of the mineral to an important extent, and they cite the work of other investigators, who have obtained similar results. Truog (22) has stated that leaching finely pulverized feldspars with sodium bicarbonate solution at pH 8.3 will result in the development of considerable base exchange capacity. A leaching process of this kind is termed "alkaline weathering," and it is considered that these conditions, favorable to formation of the base exchange compound in soils, may be simulated during periods of scanty rainfall, when the soil water tends to approach equilibrium with feldspathic minerals. With heavy rainfall well charged with carbon dioxide, the conditions are different, and might be termed "acid weathering." Kaolin is the end product of weathering of feldspars under the conditions last described. Truog suggests that liming a soil may be favorable to development of exchange capacity, since the optimum reaction for "alkaline weathering" is probably approached, at least locally and temporarily, in every limed soil.

The fact that the conclusion that liming has resulted in the development of exchange capacity is not supported by the present data for total bases exchanged when corrected for carbonates dissolved, may be due to the generally unsatisfactory nature of this correction, and in fact of all base exchange studies on soils containing carbonates, as pointed out by Magistad and Burgess (15). The procedure of these authors in leaching with an alcoholic salt solution to minimize attack upon carbonates had not appeared when this work was done.

The foregoing discussion of the effects of liming upon the exchangeable bases extracted from the soil may be supplemented by a discussion of data obtained

TABLE 5

Exchangeable bases in soil from plots of section A, lime-floats test

Expressed as milligram-equivalents per 100 gm. air-dry soil

PLOT NUMBER	TREATMENT PER ACRE PER ROTATION	EXCHANGEABLE BASES									pH
		H	Al	Mn	Ca	Mg	K	Na	Total*	NH_4 absorbed	
1	Check	5.47	0.21	0.22	2.70	0.78	0.10	0.07	9.34	8.41	5.58
2	Quicklime, 500 pounds; manure, 8 tons	2.86	0.23	0.13	4.21	1.57	0.11	0.03	8.14	8.76	6.44
3	Quicklime, 1,000 pounds; manure, 8 tons	1.60	0.19	0.05	5.45	1.90	0.06	0.05	8.23	8.77	7.13
4	Check	4.52	0.18	0.24	3.29	0.90	0.07	0.02	9.04	8.35	5.75
5	Quicklime, 2,000 pounds; manure, 8 tons	alk.	0.17	0.02	9.90	2.12	0.11	0.06	10.91	9.24	7.94
6	Limestone, 1,780 pounds; manure, 8 tons	2.04	0.27	0.04	6.60	0.84	0.09	0.10	8.57	8.88	7.05
7	Check	4.82	0.23	0.24	2.95	0.60	0.08	0.07	8.76	8.41	5.58
25	Check	6.10	0.34	0.37	1.51	0.32	0.10	0.11	8.51	8.20	5.09
26	Manure, 8 tons	6.30	0.18	0.30	1.62	0.36	0.12	0.16	8.86	8.67	5.15
Average check plots		5.23	0.24	0.27	2.61	0.65	0.09	0.07	8.91	8.34	

* Figures have been corrected for dissolved carbonate.

from an examination of samples from the lime-floats test plots. This 3-year rotation has been in progress since 1905, and the 20 years of treatment should have developed marked differences in the soil. It is unfortunate, however, that the treated plots do not receive lime alone, but also manure, whereas the checks get nothing. A plot receiving manure alone is available for comparison, but is remote from those of greatest interest at present. The data are given in table 5, and will be discussed in detail.

The 500 pounds quicklime to an acre used on plot 2 during each rotation has effected a reduction of 2.29 m.e. exchangeable hydrogen, equivalent to 2,290 pounds calcium carbonate an acre. Increase of the rate of liming to 1,000

pounds an acre has caused a further reduction in acidity, equivalent to 940 pounds calcium carbonate an acre. As might be expected, the second 500 pounds of lime has been less effective than the first. Plot 5, receiving 2,000 pounds of lime is alkaline; a calculation indicates that without lime its exchangeable hydrogen might have been 4.62 m.e., and that the additional half ton of lime to a rotation has reduced the exchangeable hydrogen by a total amount equivalent to only 1,390 pounds calcium carbonate. A comparison of plot 6, to which 1,780 pounds of ground limestone with manure is applied every rotation, with plot 3, getting the equivalent in burned lime with manure, indicates that the limestone has reduced exchangeable hydrogen by 2.68 m.e., but that the caustic lime has been more effective, reducing exchangeable hydrogen by 3.23 m.e. The reaction of the samples, as determined by the quinhydrone electrode, follows the exchangeable hydrogen quite consistently, except that manure alone has apparently increased exchangeable hydrogen by an amount of no significance in comparison with the probable error of the mean of checks, but has decreased hydrogen-ion concentration to a similar meaningless extent.

Exchangeable aluminum runs about the same in these unlimed samples as in the corresponding samples from section D, 5-year rotation, but does not show the expected reduction due to lime. Exchangeable manganese is reduced in a regular and consistent manner by lime treatment, and the limestone has been quite as effective as burned lime upon this element. Calcium and magnesium are rather variable in the checks and are affected by considerable uncertainty in corrections for dissolved carbonates, so that too much significance must not be attached to minor differences. The 500 pounds of lime on plot 2 caused a net gain of 1.31 m.e. calcium and 0.75 m.e. magnesium. The half ton of lime on plot 3 produced gains of 2.35 and 1.04 m.e., whereas the ton on plot 5 has apparently been more than proportionately effective, showing gains of 6.73 and 1.32 m.e. respectively. A comparison of burned lime on plot 3 and the practical equivalent in limestone to plot 6 apparently indicates that the limestone has been much more effective in adding exchangeable calcium, but correspondingly less effective in causing accumulation of exchangeable magnesium. The calculated net gains are 2.35 and 3.54 m.e., and 1.04 and 0.14 m.e. respectively. The difference in total bases is small, however, and the divergent effects upon the two are to be accounted for by the fact that the limestone used has been low to medium in magnesium content whereas the quicklime has generally been derived from limestone higher in magnesium, and at times has been burned dolomite. The actual amounts of each applied have been based upon analyses for total neutralizing power. Potassium and sodium are more affected by the manure applied and by crop removal than by liming, and the results do not show consistent differences attributable to lime treatment. All unlimed plots are higher in bases extracted than in ammonium absorbed, whereas, with a single exception, the opposite is true for these limed plots, as it was for those of section D, 5-year rotation. The figures for ammo-

nium absorbed indicate that the lime treatment has caused increases in total base absorptive capacity, in general, consistent with the amounts of lime applied, whether burned lime or carbonate.

SUMMARY

The 30 plots of section D, 5-year rotation at the Ohio station are of particular interest with respect to influence of fertilizers and lime upon exchangeable bases, since this is one of the oldest fertility experiments in America and is on soil of non-calcareous origin, but has had one end of the plots limed since an early date. The further fact that each third plot is a check, enabling conclusions to be drawn with more assurance of their correctness, increases the value of data from these plots. The lime-floats plots offer an opportunity to compare the effects of burned lime at several rates and of ground limestone. It is pointed out that during the 31 years that had elapsed from the start of this fertility experiment to the time of sampling the plots, there has been considerable erosion, so that on certain plots a lower horizon than the original surface is now the topsoil. This fact has a bearing upon comparisons of the recent samples with samples taken from the plots at the beginning of the experiment and still available for analysis. Other particulars of the history of the plots and their treatment are discussed, as well as the manner in which the data should be interpreted.

Auger samples from the half plots to the depth of $6\frac{2}{3}$ inches and taken in sufficient number to ensure a sample representative of the half plot were air-dried and passed through a 2-mm. sieve. One-hundred-gram portions were leached with 750 cc. normal ammonium acetate at pH 7.07 and afterwards with neutral 80 per cent alcohol. In the ammonium acetate leachings exchanged hydrogen, aluminum, manganese, calcium, magnesium, potassium, and sodium were determined, and in the residue of soil absorbed ammonia and residual carbonates. Samples of the original soil were examined for exchangeable ammonia, for carbonate, and for pH.

As the effect of a generation of cropping, shown by differences between the samples taken in 1894 and those taken in 1925, the unlimed soil is higher in exchangeable hydrogen and aluminum, and lower in manganese, calcium, magnesium, potassium, and sodium, and also lower in total base absorbent capacity. The limed soil is much lower in exchangeable hydrogen, aluminum, and manganese, and slightly lower in exchangeable potassium and sodium. The total base-absorbing capacity of the limed soil has been increased.

As to the effect of various fertilizers without lime, it may be said that exchangeable hydrogen has possibly been increased by superphosphate, but is certainly higher as the effect of sulfate of ammonia, and is probably higher as the result of using dried blood and oil meal as ammoniates. Muriate of potash is not indicated to have any effect upon exchangeable hydrogen, but nitrate of soda, nitrate of lime, and basic fertilizers such as bone meal decrease it. The tendency of manure appears to be to decrease exchangeable hydrogen,

although the indications of two plots are inconsistent; pH values vary with exchangeable hydrogen in a reasonably regular manner.

Aluminum tends to follow exchangeable hydrogen, although the quantity is so small that it is comparatively insignificant.

Manganese is little affected by fertilizers, although apparently increased by manure and by sulfate of ammonia.

Calcium in the exchangeable form is increased by fertilizers containing calcium, such as superphosphate and nitrate of lime, as well as by those fertilizers carrying alkaline calcium compounds, such as basic slag or cyanamid. Muriate of potash is without noticeable effect upon exchangeable calcium, but nitrate of soda has effected some conservation of calcium, or increased the tendency for this element to be accumulated. Manure causes a net gain in exchangeable calcium. Oil meal in complete fertilizer was favorable to conservation of calcium, dried blood less so, and sulfate of ammonia responsible for a large loss.

Magnesium has been increased by manure but heavily depleted by sulfate of ammonia.

Potassium is little influenced by fertilizers not containing it. The accumulation of potassium in the exchangeable form has been most marked on plots receiving potash alone or in an incomplete mixture, but there has been considerable accumulation on all plots receiving potash. Sixteen tons of manure to each rotation has raised exchangeable potassium to a high level, but eight tons has not done so. During the six years since complete fertilization of one plot was discontinued, exchangeable potassium in the soil has fallen almost to the same level as that of soil never fertilized. Of the potassium applied in fertilizer and probably not removed in the crops, only about a quarter appears as exchangeable potassium in the surface soil.

There has been comparatively slight tendency toward the accumulation of sodium in exchangeable form as a residue from nitrate of soda.

Figures for exchangeable ammonium are low and show little consistent variation, except that the unlimed plot receiving sulfate of ammonia is highest.

Extracted bases exceed ammonium exchanged on unlimed samples.

On limed soil, exchangeable calcium and magnesium are so greatly increased by lime treatment that there is no influence of fertilizers apparent. Potassium and sodium are similar in their indications to those of the unlimed soil, but less accumulation is evident. The larger yield produced by the limed soil is no doubt responsible for this.

The solubility of manganese is diminished in a regular manner by increasing applications of lime. Ground limestone is as effective in this respect as is the equivalent in burned lime.

The presence of calcium carbonate does not prevent the exchange of elements such as manganese and magnesium for ammonium from neutral ammonium acetate. It is pointed out that the presence of residual limestone in the soil may increase the difficulty in making accurate determinations of exchangeable

calcium and magnesium by preventing complete exchange as long as the limestone continues to be dissolved.

From the base exchange standpoint, the most interesting effect of lime treatment is the apparent building up of the exchange capacity of the soil, as indicated by increase in ammonium absorbed. The sum of exchanged and dissolved bases minus carbonate dissolved should serve as a check and permit more definite conclusions, but presumably on account of difficulties in the determinations of hydrogen exchanged by these soils containing considerable residual carbonate, the sum of exchanged bases is less than the ammonium absorbed. This building-up of absorbent capacity is indicated to be real, and not an effect due to the mere presence of carbonate, as mixtures of soil with calcium carbonate leached at once do not show it.

REFERENCES

(1) Anonymous 1924 The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 381: 245–354.

(2) Baver, L. D. 1926 The use of the quinhydrone electrode for measuring the hydrogen-ion concentration of soils. *Soil Sci.* 21: 167–179.

(3) Baver, L. D. 1927 Factors affecting the hydrogen-ion concentration of soils. *Soil Sci.* 23: 399–414.

(4) Bear, F. E., and McClure, G. M. 1920 Sampling soil plots. *Soil Sci.* 9: 65–75.

(5) Bradfield, R. 1924 The importance of hydrogen-ion concentration control in physico-chemical studies of heavy soils. *Soil Sci.* 17: 411–422.

(6) Breazeale, J. F., and Magistad, O. C. 1928 Base exchange in orthoclase. Ariz. Agr. Exp. Sta. Tech. Bul. 24: 609–629.

(7) Conrey, G. W., and Schollenberger, C. J. 1927 The effect of weathering upon exchangeable bases as shown in the Clermont silt loam profile. *Proc. and Papers First Internatl. Congr. Soil Sci. Comn. II.* 1927: 212–229.

(8) Fraps, G. S. 1929 Relation of the water-soluble potash, the replaceable and acid soluble potash to the potash removed by crops in pot experiments. Texas Agr. Exp. Sta. Bul. 391.

(9) Funchess, M. J. 1918 The development of soluble manganese in acid soils as influenced by certain nitrogenous fertilizers. Ala. Agr. Exp. Sta. Bul. 201.

(10) Hartwell, B. L., and Crandall, F. K. 1928 The substitution of stable manure by fertilizers, green manure, and peat; III. R. I. Agr. Exp. Sta. Bul. 216.

(11) Joffe, J. S., and McLean, H. C. 1927 Availability of replaceable cations. *Proc. and Papers First Internatl. Cong. Soil Sci. Comn. II.* 1927: 256–265.

(12) Kelly, W. P., and Brown, S. M. 1924 Replaceable bases in soils. Calif. Agr. Exp. Sta. Tech. Paper 15.

(13) Love, H. H. 1924 A modification of Student's table for use in interpreting experimental results. *Jour. Amer. Soc. Agron.* 16: 68–73.

(14) Magistad, O. C. 1928 The action of aluminum, ferrous and ferric iron, and manganese in base exchange reactions. Ariz. Agr. Exp. Sta. Tech. Bul. 18: 445–463.

(15) Magistad, O. C., and Burgess, P. S. 1928 The use of alcoholic salt solutions for the determination of replaceable bases in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 20: 481–497.

(16) Martin, J. C. 1929 The effect of crop growth on the replaceable bases in some Californian soils. *Soil Sci.* 17: 123–136.

(17) Merkle, F. G. 1928 The influence of fertilizer treatments on the exchangeable cations in Hagerstown silt loam. *Soil Sci.* 26: 377–384.

(18) PAGE, H. J., AND WILLIAMS, W. 1924 Studies in base exchange on Rothamstead soils. *Trans. Faraday Soc.* (no. 60) 20 (pt. 3): 573–585.

(19) SCHOLLENBERGER, C. J. 1927 Exchangeable hydrogen and soil reaction. *Science* 65 (1692 n.s.): 552–553.

(20) SCHOLLENBERGER, C. J. 1928 Manganese as an active base in the soil. *Soil Sci.* 25: 357–358.

(21) THORNE, C. E. 1919 The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 336: 581.

(22) TRUOG, E. 1928 Unpublished paper presented at meeting of American Society of Agronomy, Symposium on Application of Base Exchange Methods. Nov. 22, 1928, Washington, D. C.

THE PURDUE TECHNIQUE FOR TAKING AND MOUNTING MONOLITHIC SOIL PROFILE SAMPLES

T. M. BUSHNELL[1]

Purdue University Agricultural Experiment Station

Received for publication November 7, 1929

Soil profile samples of the main soil types of Indiana were collected in 1929 for (*a*) standards in soil survey, (*b*) instructional material of the school of agriculture, and (*c*) the Purdue exhibit at the Indiana State Fair.

As the usual "Glinka box" procedure is too laborious and costly and the samples too heavy, we planned to adapt Chapman's (3) suggestions to our requirements and to use gelatin as has been done by Pinkert (1). No gelatin was available but among materials tried as substitutes was "pad glue."

The first trial was somewhat according to the procedure we assumed was used by Pinkert, although detailed instructions were not available. A "Glinka box" sample already in the laboratory was smoothed and coated with pad glue. Instead of using a board on the glued surface then shaving the soil down to a thin, uniform, stiff layer, we pressed cloth on the hot glue, then broke away the excess soil to form a flexible sample of irregular thickness and rough surface which showed the natural structure and cleavage faces. The quality of the surface appearance was surprising to anyone acquainted with the difficulty of preparing profile faces, either in the field or on samples, to show natural faces without marring them.

To date, 22 profiles have been collected in duplicate. Plate 1 shows 7 profiles which illustrate the manner in which the structure and color horizons are revealed, and also the way leaf litter, grass, roots, sands, silts, gravels, and rocky substratum are held in these samples.

Although new details come up with each individual sample, the method from start to finish has been to glue a cloth to a soil face in place in the field, then break off the sample which is held together with the glue and cloth.

The degree of success is judged by perfection of natural horizons and structure faces of the sample and by freedom from damage. Soil materials must have some coherency and be moist enough to bond with the glue. (Perfect monoliths of incoherent material would be hard to obtain by any method.) Success partly depends upon appropriate manipulations according to the way the soil "acts."

[1] Associate in soil survey.

The apparatus and materials used were as follows:

1. Portable gasoline stove.
2. Double boiler.
3. Water.
4. Pad glue.
5. Canvas strips 48 inches by 5 inches.
6. Sample boxes 48 inches by 5 inches by 1 inch outside and 47 inches by 4 inches by $\frac{3}{4}$ inch inside.
7. Wall board 47 inches by 4 inches.
8. Spool roller 4-inch span.
9. Shovels, pick, smoother.
10. Putty knife, pocket knife.
11. Pruning shears.
12. Small sprayer.

PROCEDURE

1. Prepare a smooth and approximately vertical face of soil.
2. Heat pad glue in double boiler.
3. Outline sample face 47 inches by 4 inches with groove about 1 inch deep.
4. If sample face is too dry spray with water.
5. Roll up canvas strip and glue one end in groove at bottom of sample face, then pour hot glue between canvas and sample face, simultaneously unrolling the canvas strip and pressing it against the sample face with the spool roller until the top of the sample is reached.
6. Quickly turn the canvas around the edges of the sample face into the grooves and caulk in place with mud. The glue will stiffen sufficiently in a few minutes.
7. Cut and break off the sample from one to two inches thick, holding a wall board strip against the cloth side of the sample to prevent collapse.
8. Slide the sample into the sample box, pull out the wall board strip and glue the sample in place.
9. When the sample is in a proper moisture condition pick off excess soil with the fingers or stand the sample upright and allow the soil to fall off.

The cost of duplicate samples is as follows:

2 pounds pad glue	$0.70
2 canvas strips	.12
2 sample boxes	.50
Total	$1.32

The time cost is larger, but variable. One man may take duplicate samples in two hours. It is preferable that he have a helper at critical stages of the operation. More labor and time is required if a pit must be dug. It may take more time to find an ideal sampling place than it does actually to collect the samples.

Chapman's suggestion of taking samples from the side of post holes may be combined with the idea of using glue for binding the soil sample to either flexible or stiff backing materials. Sampling "blindly" in a post hole is little different from all other methods which reverse the face seen in the cut sampled, and expose a new surface on the face exhibited.

Schlacht (2) reports the use of a special lacquer for cementing soil to boards pressed against soil samples. Such lacquer or some other glues might be preferable to pad glue, which must be heated for use, provided their bonding power and cost are satisfactory.

A number of variations of the general scheme have been tried out or proposed for special needs.

Samples can be taken of any size or shape. Long profiles can be taken in continuous strips and rolled up without much damage. Samples can be taken in sections and pieced together. Either natural or "freak" profiles may be synthesized.

Samples have been taken by pouring glue into a very shallow metal box and pressing it into an earth wall, or by painting glue on a board and pressing it against a soil face. Such stiff backings may improve the appearance of soils that shrink too much on drying.

A light, strong profile sample in the shape of a round column with natural soil appearance on all sides may be taken as follows. Bore a vertical auger hole a few inches back of the face of a soil cut. Coat the inside of this hole with glue and force a glue-coated hollow tube into it. Dig out the sample which is supported internally by the tube.

As suggested by Pinkert, glycerin and other liquids were tried as means of preserving the moist soil color, but they spoil the structure and blend the colors of the natural faces. Colors of dry samples are true natural characteristics, even though not so commonly seen in humid regions as moist colors.

SUMMARY

The method described consists essentially of gluing cloth or other material to a soil face in the field and breaking off the sample which adhers to the glue. The method is easy, convenient, and cheap. The resulting soil samples are flexible, light, strong, and portable; but the most important point is the improved appearance, showing structure and breakage faces.

REFERENCES

(1) Anonymous. 1927 A better way of soil sampling. *U. S. Dept. Agr. Off. Rec.* 6: (38): 3.
(2) Carl, Hugo 1929 First subcommission of the fifth commission, International Society of Soil Science meets at Danzig. *Soil Sci.* 28: 177.
(3) Chapman, J. E. 1928 Monolithic soil profiles. *Science* 68: (1761) 299.

PLATE 1

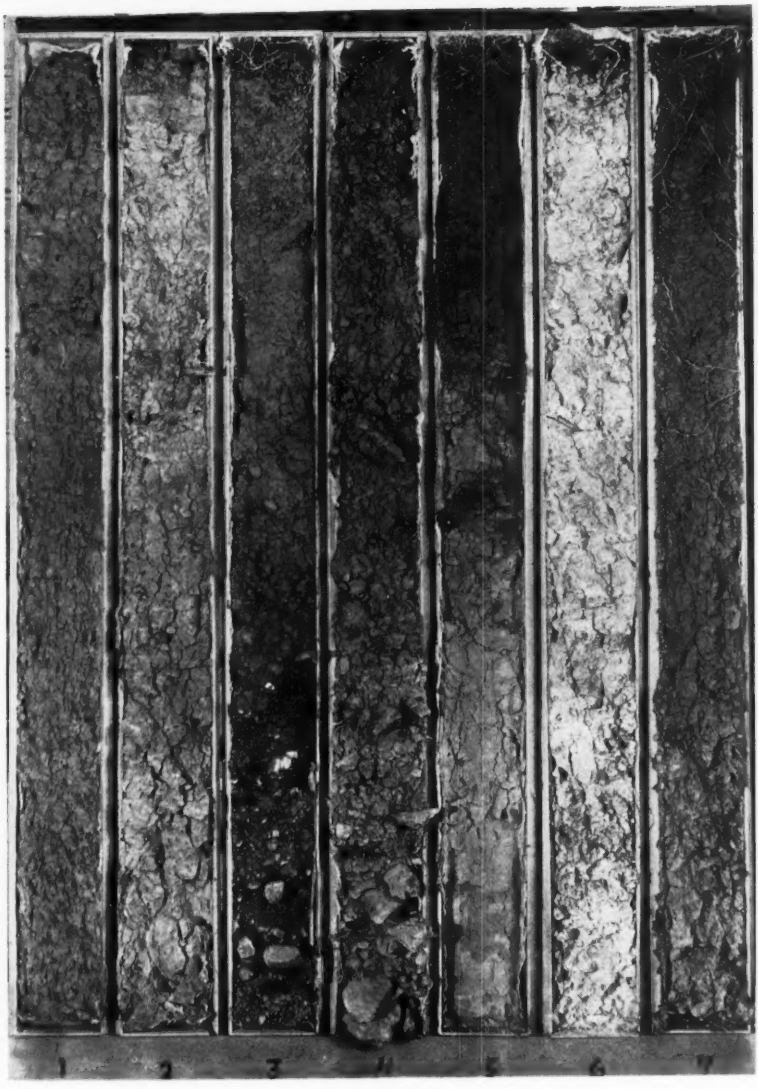
SOIL PROFILES TAKEN AND MOUNTED BY THE PURDUE METHOD

No. 1, Wabash silt loam; No. 2, Crosby silt loam; No. 3, Fox silt loam; No. 4, Fairmount silty clay loam; No. 5, Maumee fine sandy loam; No. 6, Clermont silt loam; No. 7, Webster silt loam.

TAKING SOIL PROFILE SAMPLES

T. M. BUSHNELL

PLATE 1



THE APPROXIMATE SIZE OF SOIL PARTICLES AT WHICH THE HEAT OF WETTING IS MANIFESTED[1]

LAWRENCE C. KAPP[2]

Michigan State College of Agriculture

Received for publication November 7, 1929

There is a general tendency on the part of soil scientists to attribute the major portion of the reactivity of soils in various respects to the colloidal fraction or portion (2, 4, 11, 12, 15, 16, 18). Since Schloesing (23, 24) called particular attention to the colloidal matter in soils, investigators have accumulated a large amount of data on this subject. It is obvious that if the results obtained by different workers are to be more strictly comparable than they are at present, a more definite system of classification is necessary. It appears that the size of particle is most commonly employed in differentiating the colloidal from the non-colloidal materials in soils. It must be admitted, furthermore, that different sized limits have been suggested and employed in the classification of soil particles into colloidal and non-colloidal material but at present this classification is merely an arbitrary one.

König and Hasenbäumer (14), Ogg and Hendrick (19), and Atterberg (3) present data to show that the absorption by the different sized particles of a soil increases with the fineness. Since the various soil fractions probably were not freed entirely from colloidal material, the determinations cannot be accepted without doubt. Anderson et al. (2) states that five per cent of the total absorption of a soil is due to the non-colloidal material when calculated from the absorption of mineral powders and mineral composition of a soil. Their data show that the three separates of soils; coarse fraction, fine fraction — 0.001 to 0.05 mm. in diameter, and colloidal material — 0.001 mm. in diameter to smaller, had absorptive values and that the non-colloidal material is responsible for 20 to 70 per cent of the total absorptive capacities of the four soils. If the absorption method of determining the colloidal content of a soil is correct, these data show that the material considered before as non-colloidal material possesses the property of absorption and is included with the determined colloidal material.

[1] A portion of a thesis submitted to the graduate committee at Michigan State College as partial fulfillment of the requirement for the degree of doctor of philosophy.

[2] Formerly graduate assistant in soils at the Michigan State College of Agriculture and Applied Science, now assistant in agronomy, University of Arkansas, Fayetteville, Arkansas.

As the heat of wetting method (1, 16) for the determination of the colloidal content of a soil,

$$\frac{\text{heat of wetting of soil per gram}}{\text{heat of wetting of colloid per gram}} \times \frac{100}{1} = \text{per cent colloids in soil}$$

is also based on a colloidal property, possibly it measures as colloidal material the particles which we consider as non-colloidal in size. Bouyoucos (9) states that recent studies on the heat of wetting of soils indicate that the finer silt separates or part of that portion considered before as non-colloidal material manifests the heat of wetting property. In the studies of soils by the hydrometer method he includes the fine silt in the colloidal content of a soil as he believes that the material which exhibits the property of heat of wetting should be spoken of as colloidal material, regardless of the size of particles.

Since the previous investigations on absorption of the colloidal and non-colloidal materials of a soil do not indicate the size at which the line can be drawn to separate the two constituents it was considered advisable to separate different soils into different size separates as accurately as possible and to ascertain by the heat of wetting method the size at which the soil material ceases to give any heat of wetting, and to classify the soil material into colloidal and non-colloidal according to the phenomenon of heat of wetting. As the soil is a heterogeneous mass of minerals, it was thought that it would be interesting to grind several minerals and divide them into the different separates to be compared with the soil separates. In this manner interesting facts have been obtained on the approximate size of soil particles at which the heat of wetting ceases to be manifested.

EXPERIMENTAL PROCEDURE

The heat of wetting was measured according to the method described by Bouyoucos (4). It consisted of placing 25 to 50 gm. of air-dried material in a wide glass tube and drying it in an electrically heated oven at a temperature of 110°C. for 24 hours. The tube was removed, closed with a rubber stopper, and allowed to attain the room temperature. After exact readings of weight and temperature were observed, the soil was quickly and carefully poured into a calorimeter containing 100 gm. of water. Extreme care was exercised before mixing to have both the soil and water at exactly room temperature. In order to be able to convert, if necessary, the rise of temperature into heat calories, the water equivalent of the calorimeter was determined. This was found to be 25 gm. of water. For the specific heat of the material used in this work, the value of 0.2 was employed throughout. This value was used for the mineral separates as well as for the soil separates, because Regnault, Joly, Bartholi, and Pionchon (21) found this value for different mineral powders many years ago.

The temperature of a gray soil was used as a standard for obtaining the temperature of the materials used in each determination. This gray soil had

been subjected to the same conditions of heating and cooling as the other materials. Suppose that the temperature of the gray soil was 0.05°C. lower than that of the other materials used. As the specific heat is 0.2 calorie to each gram, the water would be increased 0.01 calorie for each gram added to the calorimeter. Therefore, when 20 gm. of material was used the increased heat transferred to the water would be only 0.2 calories. It is impossible to read this increase in 100 gm. of water. Therefore, the small difference in temperature between the standard and the materials used would not affect the results to a measurable extent.

The thermometers used were checked against each other. They could be read within 0.025°C. and slightly less with the aid of a reading glass. Therefore, if the heat of wetting was only 0.2 calorie a gram and 20 gm. were used, the increase in temperature would be only 0.031°C. on the determination thermometer. This increase in temperature could be read quite easily.

If extreme care is used, the temperature of the water in the calorimeter would never be higher than that of the separates. In every case it would be lower, because of the cooling effect by evaporation from the water surface and wet parts of the calorimeter.

After the above sources of error are considered, it appears logical to believe that 0.2 to 0.3 calorie to a gram of material can be attributed to experimental error for each determination. The soils were first treated with 1:4 hydrochloric acid to decompose the carbonates present and remove the bases as chlorides. As the carbonates do not possess the property of heat of wetting, their presence has a decided effect upon the heat of wetting produced by a soil, in that it reduces the weight of soil and thus gives a low heat of wetting determination for a gram of soil material. Pate (20) has shown that monovalent bases in a soil decreased the heat of wetting as much as 46 per cent in some cases. The divalent bases do not exert such a pronounced influence.

As organic matter gives a high heat of wetting, as much as possible was removed by hydrogen peroxide to obtain samples suitable for the determinations. Neither certain other chemicals of heat could be used, as they would destroy to some extent the heat of wetting property of the soils. Robinson (22) in his recent work on the hydrogen peroxide method of oxidizing organic matter in soils, states that the variety of soils and colloids containing 0.42 to 95.85 per cent of organic matter shows that practically all the organic matter can be decomposed in some soils and that in other soils considerable is left unattacked.

The hydrogen peroxide used was Merck Superoxyl, a commercial product containing 30 per cent hydrogen peroxide. The dilute hydrogen peroxide treated soils were heated on a steam bath until the effervescence ceased and more concentrated solution could be used. Finally the concentrated peroxide was used. The soils were then transferred to a Buchner funnel and washed free from the organic compounds formed. The minerals were ground by hand in an agate mortar. It was realized that the only mineral to be contaminated

by this procedure would be the quartz, as it has the same hardness as agate and as agate is a quartz this contamination is not unsatisfactory. The other minerals used have a hardness below that of agate.

The soils and minerals were then separated by the application of Stokes' law. This law has been adopted by the International Society of Soil Science as an aid in the mechanical analysis of soils. The soils were dispersed daily in a special dispersion machine described by Bouyoucos.

After each dispersion, the soil was placed in a liter beaker which was filled with distilled water to a depth of 13 cm. The temperature was taken and after certain intervals of time (shown in table 1) had elapsed, the particles in suspension were siphoned off by using a glass tube having a side hole at the lower end. This was used to avoid drawing into the tube the particles which had already settled to the bottom. In order to obtain the small particles, the siphoned suspension consisting of the finest soil separates was placed on a

TABLE 1

Time required for particles of different sizes to settle 13 cm.

TEMPERATURE	COEFFICIENT OF VISCOSITY OF WATER	TIME REQUIRED BY					
		0.00125-mm. particles	0.005-mm. particles	0.01-mm. particles	0.02-mm. particles	0.035-mm. particles	0.05-mm. particles
°C.		*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
20	0.01005	1550.40	96.96	24.24	6.06	1.98	0.9696
21	0.0098	1512.60	94.54	23.63	5.91	1.93	0.9454
22	0.00958	1479.60	92.42	23.10	5.77	1.89	0.9242
23	0.00936	1444.80	90.30	22.57	5.64	1.84	0.9030
24	0.00915	1412.40	88.27	22.07	5.52	1.80	0.8827
25	0.00894	1380.00	86.25	21.56	5.39	1.76	0.8625
26	0.00875	1350.60	84.41	21.10	5.28	1.72	0.8441
27	0.00856	1321.20	82.58	20.64	5.16	1.70	0.8258

steam bath to evaporate the large amount of water. The large particles were obtained by siphoning off the supernatent liquid after sedimentation of the particles.

The formula used in calculating the size of the particles at various rates of falling is as follows:

$$v = \frac{2 \times g \times d^2 \times (s - s_1) \times 6}{9 \times nt \times 40}$$

v = distance in centimeters of a particle of d size to fall in one minute.
d = diameter of particle in millimeters.
s = specific gravity of material used.
s_1 = specific gravity of water.
nt = coefficient of viscosity of the water at given temperature.
g = force of gravity or 980 dynes.
2/9 = factor expressed in Stokes' original law.
6/40 = factor used to express v in terms of centimeters per minute when diameter is in millimeters.

As $v = \frac{\text{cm.}}{t \text{ in minutes}}$ as well as the formula above, and as we are interested in finding the time, the equation becomes

$$t \text{ in minutes} = \frac{\text{cm. depth of liquid} \times 9 \times \eta t \times 40}{2 \times g \times d^2 \times (s - s_1) \times 6} \qquad (A)$$

The value of s changes for different minerals, but for the soil separates 2.65 was always used.

Table 1 was calculated by the general formula (A) for a depth of 13 cm. of water for the different size separates.

In the process of separation by the application of Stokes' law, the concentration of the material in water was never allowed to exceed five per cent by weight. By keeping the concentration below five per cent, the errors due to the friction of the solid particle in suspension upon each other would not be encountered. As the different minerals used had different specific gravities, a table similar to table 1 was calculated for each mineral.

EXPERIMENTAL RESULTS

Table 2 presents the data obtained on the heat of wetting of different soil separates, expressed as calories a gram of material. The heat of wetting ceases entirely to be manifested for the separate 0.035 to 0.05 mm. in diameter for each soil except the Missouri soil. In soil separate 0.02 to 0.35, only four soils gave a heat of wetting above the considered experimental error. In the 0.005 to 0.02 separate, only three of the determined soils were decidedly above the experimental error. The Missouri soil shows a heat of wetting of 1.11 calories a gram in the 0.005 to 0.02 separates. The Florida soil separate gave a heat of wetting of 3.85 calories for the 0.005 to 0.02 mm. in diameter separate. In the 0.005 to 0.01 separate column, it is noticed at once that all but one of the soils give a decided heat of wetting. In this separate, the Florida and Missouri soils would be expected to give high heats of wetting as their clay separates and their next finer separate size give a high heat of wetting. Therefore, separates having as low a heat of wetting as 0.2 ot 0.3 are too small to be regarded as significant as they are within experimental error. After the low heat of wetting readings were disregarded, therefore, the separate 0.005 to 0.01 is the only one that should be regarded as giving a heat of wetting that is doubtless true.

These data confirm Bouyoucos' (9) contentions, as stated previously, that the finer silt should be included in colloidal material, as it gives the heat of wetting property similar to that of clay and the colloid separates, but only in a different degree.

Table 3 presents the heat of wetting expressed as calories per gram of the mineral separates obtained. It is noticed that all the ground mineral separates give a definite heat of wetting in the fine material, or for particles smaller than 0.005 mm. in diameter. The pure zicron mineral gave a heat of wetting of over 0.3 calorie a gram in the 0.005 to 0.01-mm. separate. The biotite gave

0.35 calorie for the 0.02 to 0.35-mm. separate but the heat of wetting of the remaining larger particles is within the experimental error and should not be considered significant. The hornblende shows a large heat of wetting even in the particles larger than 0.05 mm. in diameter. This heat of wetting, 1.26 calories a gram, cannot be disregarded, as hornblende is a constituent of many soils and must play an important rôle in the heat of wetting of soils as a whole. Cushman (10) suggests that a colloidal film is formed on the surface of some minerals because of the formation of insoluble hydrolytic products of a colloidal

TABLE 2

Heat of wetting of soil separates expressed as calories per gram of material

SOILS	HEAT OF WETTING							
	Colloids†	Clay‡	0.005–0.01-mm. particles	0.005–0.02-mm. particles	0.01–0.02-mm. particles	0.02–0.035-mm. particles	0.035–0.05-mm. particles	0.05–1a-mm. particles
	calories	*calories*	*calories*	*calories*	*calories*	*calories*	*calories*	*calories*
Iron Mountain	6.56	2.44	0.65	0.65	0.45	0.25	0.00	0.00
Napanee	4.12	1.32	0.43	0.33	0.00	0.00	0.00	0.00
Ontonagon	6.50	2.57	0.43	0.22	0.20	0.00	0.00	0.00
Florida	15.42	8.43	....	3.85	....	....	0.00	0.00
Miami	5.61	3.16	0.42	0.34	....	0.15	0.00	0.00
Soil	....*	....	0.91	....	0.62	0.36	0.00	0.00
Missouri	18.22	6.02	....	1.11	....	0.54	0.36	0.36
Gray Soil	5.45	....	....	0.32	....	0.00	0.00	0.00
Silt	....	....	....	....	....	0.00	0.00	0.00
Brookston	5.32	1.40	0.74	....	0.17	0.00		
Isabella	2.13	1.40	0.44	....	0.22	0.00		
College Farm	5.63	2.83	0.32	....	0.26	0.00		
Hillsdale	6.48	4.05	0.85	....	0.40	0.00		
Chippewa	5.63		0.65	....	0.00	0.00		

* The blanks indicate that the amount obtained was insufficient for a determination.

† Colloids 0.00125 mm.—Molecular dimensions in diameter.

‡ Clay 0.005–0.00125 mm.

nature. This may be the explanation of the hornblende and biotite minerals giving a higher heat of wetting than the other minerals shown in the table. The results recorded show that different minerals exhibit the property in different degrees. This bears out the theory of Harkins and Ewing (13) that the quantity of the heat of wetting of a colloid is indicative of the nature of the material. The compression force is considered to be due to the attraction force between the molecules of the liquid and the molecules of the absorbent. The heat evolved by wetting is due largely to the heat of the compression of absorbed liquid. Bouyoucos (7) has shown that the force with which the soils

absorb and probably compress the water that produces the heat of wetting is very high.

In comparing tables 2 and 3, it is observed that the soil separates are larger in diameter than the mineral separates where the heat of wetting property ceased to be obtained. This would be expected, because the soil particles are probably more porous and have an increased degree of activation due to weathering processes. It is probable that the organic matter and gels had not

TABLE 3

Heat of wetting expressed as calories per gram of the mineral separates

SOILS	HEAT OF WETTING						
	0.005-mm. small particles	0.005–0.02-mm. particles	0.02–0.35-mm. particles	0.035–0.05-mm. particles	0.035-mm. larger particles	0.05-mm. larger particles	0.005–0.035-mm. particles
	calories	*calories*	*calories*	*calories*	*calories*	*calories*	*calories*
Hornblende	5.80	....*	2.51	....	1.43	1.36	2.38
Crystallite	2.07	0.23	0.32	0.20	....	....	....
Biotite	2.80	0.85	0.35	0.16	0.00	0.00	....
Apatite	2.10	0.16	0.00	0.00	0.00	0.00	0.00
Quartz	1.15	0.00	0.00	0.00	0.00	0.00	0.00
Biotite and Quartz	....	0.37	0.00	0.00	0.00	0.00	0.00
	Colloid	Clay	0.005–0.01-mm. particles	0.01–0.02-mm. particles	0.02–0.035-mm. particles	0.035-mm. larger particles	
Granite	1.60	0.30	0.00	0.00	0.00	0.00	....
Zicron	2.45	1.15	0.325	0.00	0.00	0.00	....
Napanee Sand, 0.05—larger	1.22	0.27	0.00	0.00	0.00	0.00	....
Ontonagon Sand, 0.05—larger	1.99	0.49	0.00	0.00	0.00	0.00	....

* The blanks indicate that the amount obtained was insufficient for determinations.

been entirely removed, or that some particles are coated with hydrolytic products of minerals similar to hornblende.

As was stated previously, all the organic matter is not removed from some soils by treatment with hydrogen peroxide. Since the organic matter particles have a lower density than the soil particles, we would expect to find most of the small particles of organic matter in the fine separates.

In order to ascertain whether the separates, after being treated with hydrogen peroxide, still contained organic matter, their nitrogen content was determined. Table 4 shows the percentage of nitrogen remaining in the soil separates as determined by the Cunning-Hibbard method for total nitrogen. All the

nitrate nitrogen had previously been removed by repeated washings, as determined by the colorimetric method. Table 4 shows that the fine materials contain the largest amount of total nitrogen. In every case, except the Missouri soil, the colloid separate contained more nitrogen than the clay separate. McCool et al. (17) showed that the fine soil material gives a high

TABLE 4

Percentage of nitrogen in the separates after being treated with "superoxyl"

SOILS	NITROGEN CONTENT						
	Colloids	Clay	0.005-mm. smaller particles	0.005-0.01-mm. particles	0.005-0.02-mm particles	0.01-0.02-mm. particles	0.02-0.35-mm. particles
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Missouri	0.13443	0.269	0.094	....	0.015	....	0.011
Brookston	0.058	0.046	.....	0.016	....	0.008	0.007
Isabella	0.313	0.063	....	0.025	....	0.007	0.012
College Farm	0.261	0.069	....	0.019	....	0.011	0.007
Hillsdale	0.077	0.090	....	0.032	....	0.022	0.014
Chippewa	.....	....	0.069	0.027	....	0.017	0.007

TABLE 5

Calories per gram of soil colloids and three minerals (0.005 mm. to smaller) at different temperatures of ignition

MATERIAL	CALORIES PER GRAM				
	110°C.	308°C.	405°C.	530°C.	830°C.
Napanee	3.88	2.75	2.13	1.41	0.00
Iron Mountain	6.91	6.41	5.31	4.38	0.00
Ontonagon	6.54	4.89	3.96	3.26	0.00
Kewanee	3.61	3.53	2.01	1.61	0.00
Florida	15.40	10.64	9.00	6.95	0.00
Kaolin	1.24	1.25	1.28	1.40	0.23
Limonite	1.12	3.48	3.06	2.65	0.49
Silica (precipitate)	5.90	5.25	4.91	4.10	0.90

heat of wetting and has a higher nitrogen content than the coarse material. In the Missouri soil the clay had the highest nitrogen content. The separates 0.005 to 0.01 mm. in diameter also give a fairly high percentage of nitrogen. It is very uncertain whether the organic matter present, as found by the total nitrogen determination, causes the difference between the heat of wetting of a soil separate of a given size and the corresponding mineral separate, provided the number of particles of each size was equal in both cases. Although the

organic matter is known to possess a high heat of wetting property, it is doubtful whether it had a noticeable effect in the different silt separates, for the heats of wetting are all low, although organic matter is shown to be present. It may be concluded that the organic matter present is resistant to wetting and therefore fails to give a measureable heat of wetting. The results tend to show that the organic matter and gels, if present, do not in any case seem to have a marked effect upon the heat of wetting of the silt separates and should be considered as insignificant.

Since the soils are conglomerations of different minerals, it was thought that possibly hornblende, biotite, and similar minerals in the soil would coat the other particles as well as themselves with a hydrolytic colloidal coating and thus increase their heat of wetting property. Several samples of different soil separates and mineral separates were treated for 10 days with hornblende particles less than 0.005 mm. in diameter in suspension. At the end of this

TABLE 6

Per cent of different size particles after materials were heated to 830°C.

SOILS	0.005-MM. SMALLER PARTICLES	0.005–0.02-MM. PARTICLES	0.02-MM. LARGER PARTICLES
	per cent	*per cent*	*per cent*
Napanee	1.35	3.79	94.85
Iron Mountain	1.40	2.00	96.50
Ontonagon	3.31	3.68	92.74
Kewanee	6.60	1.19	92.62
Florida	0.60	3.40	96.00
Kaolin	1.24	2.60	97.24
Limonite	0.22	8.58	91.26
Silica	5.55	5.20	89.20

time, the fine hornblende particles were separated by sedimentation and the heat of wetting was determined. No increase in heat could be detected.

Since the fine material of the soils and minerals was present, it was decided to determine the effect of ignition on the heat of wetting property. Bouyoucos (5) has shown that at 800°C. the physical properties of soils, such as plasticity, heat of wetting, and unfree water, completely disappear. The separates at hand were heated at different temperatures up to 830°C. in an electric muffle furnace. Table 5 shows the gradual decrease in the heat of wetting property after exposure to higher temperatures. All of the materials except limonite decreased gradually until at 830°C. only the Kaolin, limonite, and silica gave any heat of wetting. The limonite at 110°C. gave a heat of wetting of 1.12 calories a gram, at 308°C. it gave 3.48 calories a gram, and then gradually decreased until at 830°C. it gave 0.49 calories a gram. This is interesting because there was an increase and then a decrease after the addition of heat. We know that there are many forms of the oxide of iron, their only difference

in chemical composition being the water of hydration. In heating the limonite to 305°C. some water may have been driven off or the material chemically changed. It is doubtful whether, by dehydrating it, we had decreased the size of the particles materially. Therefore, the increase in heat of wetting to a gram of material must have been due to a physical change of the surface caused by a chemical change through the ignition process. This rearrangement of molecules on the surface, or change of surface, due to the loss of water gave the material a greater attraction force for the water and thus increased the heat of wetting.

Each material was heated in the muffle furnace and then allowed to cool at room temperature before being placed in the heat of wetting tube and heated to 110°C. in the electric oven. It was thought that by this procedure the moisture content would be the same in each case as it was originally, provided that no other changes had taken place during the ignition up to 830°C.

But why did the materials decrease in their heat of wetting property, as is shown by the other minerals and soil separates in table 5.

Since one observes that the sharp edges of a jagged piece of glass will fuse long before the main piece of glass, it was thought that possibly the small particles had fused together. The substances were then placed in distilled water and separated by the application of Stokes' law to determine whether the particles had increased in size. Table 6 shows the particles of different sizes after being heated to 830°C. In every case 89 per cent or more of particles over 0.02 mm. in diameter was left in each sample. This would indicate that the particles had fused together and as the particles become larger the heat of wetting decreased. The particles present after heating, as shown by separation, indicated that different minerals and soil particles have different fusion points. The silica has a high fusion temperature; therefore it lost its heat of wetting property gradually as the size increased, but at 830°C. the heat was not sufficient to form all particles that give no heat of wetting. In the case of soils, their composition is heterogeneous. They contain some minerals that will fuse at a low temperature and will thus coalesce with the minerals that have not fused. By doing so the size of the particles will increase proportionally to the number of low or high fusion minerals present in the sample.

The Florida colloid and Kaolin mineral after being heated and separated into their different size particles were reground by hand to try to restore their original heat of wetting. The heat of wetting of Kaolin was increased to 0.82 calories a gram and that of the Florida sample was increased from 0 calories to 1.53 calories a gram. This is very small, indeed, when one remembers that the heat of wetting of the Florida material was 15.4 calories, a gram before being heated. Still, one must consider that those particles were very small and a larger amount of energy must be expended to break down a particle 0.02 mm. in diameter to 0.005 mm. and smaller.

There is no doubt, of course, that the soil material which gives rise to the phenomenon of heat of wetting is the colloidal matter and the degree of activa-

tion developed by the weathering processes. Therefore, one would not expect to restore the original heat of wetting of the Florida soil by grinding by hand.

SUMMARY

In this paper it was proposed to show the size of particles from different soils at which the heat of wetting property ceased to be manifested. In order to obtain suitable samples of different soil separates from soils for heat of wetting determinations, they were treated with 1:4 hydrochloric acid to remove the carbonates present, and with hydrogen peroxide to remove the organic matter. The soils thus treated were separated by applying Stokes' law of sedimentation.

All the soil separates give a heat of wetting in the finer silt separate and a few possess this property in the coarse material, 0.02 to 0.35 mm. in diameter. It appears that the fine silt, 0.005 to 0.01 mm. in diameter, should be included in the colloidal content of the soil as it possesses the property of heat of wetting.

Pure minerals finely ground and separated did not give such a high size limit as the soil at the place where the heat of wetting ceased. Hornblende and biotite gave a high heat of wetting even in the large silt particles. In most cases the heat of wetting ceased above particles 0.005 mm. in diameter.

The amount of nitrogen in the soil separates varies. Larger amounts of nitrogen, and, therefore, organic matter, were found in the colloidal material of the soil. This organic matter may account for part of the heat of wetting above that of the same size mineral separates. In each case, however, the organic matter present in the silt separates should not affect to a great extent the heat of wetting, for they were treated with concentrated hydrogen peroxide to remove the organic matter. The separates containing the largest amount of nitrogen do not give the highest heat of wetting.

Soil materials 0.00005 mm. in diameter to molecular in size and finely ground minerals were ignited to 830°C. to determine why the heat of wetting was destroyed. After they were heated to 830°C. and divided into the different size separates, it was found that in every case the percentage of particles 0.02 mm. in diameter was over 89.

The separates of one soil consisting of the smallest particles 0.00005 mm. in diameter to molecular in size—and one mineral finely ground to give 1.24 calorie a gram were reground after ignition, and the heat of wetting was partly restored.

REFERENCES

(1) ANDERSON, M. S. 1924 The heat of wetting of soil colloids. *Jour. Agr. Res.* 28: 927–937.

(2) ANDERSON, M. S., ET AL. 1922 The absorption by colloidal and non-colloidal soil constituents. U. S. Dept. Agr. Bul. 1122.

(3) ATTERBERG, A. 1912 Die Mechanische Bodenanalyse und die Klassifikation der Mineralböden Schwedens. *Internatl Mitt. Bodenk.* 2: 312–342. [Cited from Anderson, M. S. et al. (2).]

(4) BOUYOUCOS, G. J. 1923 The effect of ignition at various temperatures upon certain physical properties of soil. *Soil Sci.* 17: 135–139.

(5) BOUYOUCOS, G. J. 1925 The heat of wetting as a new means of estimating the colloidal material in soils. *Soil Sci.* 19: 153.

(6) BOUYOUCOS, G. J. 1925 Heat of wetting of soils dried at different temperatures and the force at which soils absorb water. *Soil Sci.* 20: 67–72.

(7) BOUYOUCOS, G. J. 1925 The effect of the colloidal content upon the physical properties of soils. *Jour. Amer. Soc. Agron.* 17: 285–294.

(8) BOUYOUCOS, G. J. 1927 The hydrometer as a new and rapid method for determining the colloidal content of soils. *Soil Sci.* 23: 319–331.

(9) BOUYOUCOS, G. J. 1928 The hydrometer method for studying soils. *Soil Sci.* 25: 365–369.

(10) CUSHMAN, A. S. 1905 The effect of water on rock powder. U. S. Dept. Agr. Bur. Chem. Bul. 92.

(11) FAILYER, G. H., ET AL. 1908 The mineral composition of soil particles. U. S. Dept. Agr. Bur. Soils. Bul. 54.

(12) HALL, A. D., AND RUSSELL, E. J. 1911 Soil Surveys and soil analysis. *Jour. Agr, Sci.* 4: 199.

(13) HARKINS, W. D., AND EWING, D. T. 1921 A high pressure due to absorption and the density and volume relation of charcoal. *Jour. Amer. Chem. Soc.* 43: 1787–1802.

(14) KÖNIG, J., AND HASENBÄUMER, J. 1920 Die Bedeutung neuer Bodenforschungen für die Landwirtschaft. *Landaw Jahrb.* 55: 185–252. [Cited from Anderson, M.S. et al. (2)].

(15) LYON, T. L., AND BUCKMAN, H. O. 1922 The Nature and Properties of Soils, p. 87. New York.

(16) MCCOOL, M. M., AND WHEETING, L. C. 1924 The influence of the removal of colloids on some soil profiles. *Soil Sci.* 18: 99–102.

(17) MCCOOL, M. M. ET AL. 1927 Further sudies on Michigan soil profiles with special references to dispersed materials. *Soil Sci.* 23: 391–397.

(18) MITSCHERLICH, E. A., AND FLOESS, R. 1912 Ein Beitrag zur Bestimmung der Hygroskopizität und zur Bewertung der physikalischen Bodenanalyse. *Internatl. Mitt. Bodenk.* 1: 463–480. [Cited from Anderson, M. S. et al. (2).]

(19) OGG, W. S., AND HENDRICK, J. 1920 Studies of a Scottish drift soil. *Jour. Agr. Sci.*, 10: 333–335.

(20) PATE, W. W. 1925 The influence of the amount and nature of the replaceable bases upon the heat of wetting of soil colloids. *Soil Sci.* 20: 329–337.

(21) REGNAULT, JOLY, BARTHOLI, AND PIONCHON The heat evolved when liquids are brought in contact with powders. *Phys. Res.* 13: 48–54. [Cited from Linebarger, C. E. 1901.]

(22) ROBINSON, W. O. 1927 Determination of organic matter in soils by means of hydrogen peroxide. *Jour. Agr. Res.* 34: 339–356.

(23) SCHLOESING, C. T. 1870 Sur la precipitation des limons par des solutions salines très etendues. *Compt. Rend. Acad. Sci. (Paris)* 70: 1345–1348.

(24) SCHLOESING, C. T. 1874 Determination de l'argile dans la terre Arable. *Compt. Rend. Acad. Sci. (Paris)* 78: 1276–1279.

BOOK REVIEWS

The Nature and Properties of Soils. A College Text of Edaphology. By T. Lyttleton Lyon and Harry O. Buckman, Professors of Soil Technology, Cornell University. The Macmillan Company, New York, 1929. Revised edition, pp. XIV + 428, figs. 33, tables 78. Price $3.50.

To those acquainted with the previous volumes by these authors the book requires little comment other than that this is a completely revised edition of the volume published in 1922. Some of the material originally presented is omitted, much new information is introduced, and the arrangement of the subject matter is changed. This edition retains most of the desirable characteristics of the former and is improved by the inclusion of much recent information, as evidenced by the numerous citations of references to scientific information published in 1929.

In the revision, many methods of procedure have been eliminated from the text and attention has been focused more on the principles upon which the methods are based. The discussions of soil formation and classification as well as of organic matter in its various relations in soils are greatly changed from the previous edition.

The book has 18 chapters as compared with 26 chapters before revision. The amount of the text is proportionally reduced, possibly improving the book for student use. The fundamental properties and reactions of soils are considered together with suggestions for their application to agricultural practice. The chapter titles of the book are as follows: 1. A fundamental conception of the soil; 2, the supply and availability of plant nutrients in mineral soils; 3. the soil particles and the physical nature of mineral soils; 4. The organisms in the soil; 5. The organic matter of mineral soils; 6. The methods of fertility maintenance for mineral soils; 7. The formation of mineral soils and the origin of soil materials; 8. Classification of soils and the soil survey; 9. The nature and utilization of organic soils; 10. Forms of soil-water and their significant physical relationships; 11. The plant relationships of soil-water and methods for its control; 12. Water as a solvent—the soil solution and its nutrient losses; 13. The soil reaction, soil acidity, and alkalinity; 14. Liming the soil; 15. The nitrogen economy of soils; 16. Fertilizers and fertilizer practice; 17. Green-manures and their management; 18. Farm-manure and its utilization. A subject index follows.

As a whole, the book is comprehensive, well balanced, and presents the extensive information related to soils and their utilization in well-digested form with a minimum of errors, all of which bears evidence of great care in reworking the material through several editions.

Principles Of Soil Technology. By PAUL EMERSON, Associate Professor of Soils, Iowa State College. The Macmillan Company, New York, 1930. Pp. XV + 402, figs. 34, tables 49 in text; charts 9, tables 32 in appendix.

This volume has much in common with the book by Professors Lyon and Buckman, reviewed in the foregoing. It deals with soil as a medium for plant growth and treats the subject material in such a manner that it may be readily utilized by soils students who have a substantial training in the natural sciences. As stated in the preface: "The writer has aimed to correlate the facts of soil knowledge and present the science from the teaching standpoint in as fundamental a manner as possible."

The book is divided into 25 chapters, which are arranged under four headings: 1. Soils In General: Their Formation and Classification; 2. The Physical Properties And Functions Of Soils; 3. The Chemical Properties And Functions Of Soils; 4. Soil Biology. Part 1 includes a consideration of soil formation, genesis, morphology, and classification, and soil areas of the United States. In part 2 the subject matter deals with soil texture, colloids, air, temperature, water, and relationships of physical properties to plant growth. Part 3 deals with soil composition, reaction, organic matter, and solution, and with relationships of these factors to plants. In part 4 the author discusses the soil population, its functions, limitations to its development, and its relationships to plants. The concluding chapter of the book deals with "Soil Cycles" and develops ideas concerning the complex relationships of physical, chemical, and biological forces in their action on soil materials and relationships to plants. A glossary of many terms used in characterizing soils is included in an appendix. The book is concluded with author and subject indexes.

The material is well organized and presented in a very interesting manner which should not fail to attract the reader by reason of its apparently successful attempt to portray the soil in its significantly important rôle in the existence of living things. Although the author includes a consideration of many of the recently developed ideas concerning soil classification, colloids, and reaction, the general treatment of the subject matter is along paths well developed by preceding students of soils. Although introducing the ideas of the modern school of pedologists, this book is not a pedological treatise. On the other hand this is not a book on soil management although it considers soil conditions suited and unsuited for economic plant development. It is adapted for the agriculturalist who wishes to become familiar with the fundamentals of soils in their relationships to plant growth.

There are undoubtedly individuals who will take exception to certain ideas expressed in the book. Typical examples of such ideas are the following: (p. 290)—"In reality, complete decomposition is the same as complete ignition; the only difference is in the time involved;" (p. 293)—"The action (nitrification) has been attributed to two groups of organisms, the nitrite-formers being called nitrosomonas and the nitrate-formers nitrosococcus. A third group, nitrobacter, is assumed to be able to oxidize the ammonia directly to the nitrate."

It is concluded (p. 313) that peat materials do not decompose because of the saturation of waters with "metabolic products which acting as toxins serve to limit biological processes" (p. 308)—"These organisms (autotrophic) are (from the standpoint of their relations to the production of food or higher plants) possibly the most important group of soil microorganisms;" (p. 309)—"These organisms (heterotrophic) cannot synthesize either carbon or nitrogen from inorganic sources;" (p. 334)—"The body of the microorganism, however, is not of itself resistant to decomposition but . . . . is reduced to the simplest combinations by the process of self-digestion, autolysis."

It is not the intention of the reviewer to overemphasize the points open to criticism. The comparatively small number of such discrepancies will undoubtedly be corrected in subsequent editions, which seem destined for such a useful book.

The Major Soil Divisions of the United States. A Pedologic-Geographic Survey. By LOUIS A. WOLFANGER, Economic and Soil Geographer, Columbia University. John Wiley and Sons, Inc., New York, 1930. Pp. XVIII + 150, frontispiece, fig. 1, tables 6. Price $2.00.

Information concerning the application of the newer ideas of soil formation and classification to the soils of the United States is widely scattered and as a rule, relatively unavailable to the general reader. The author has brought together considerable of this information for the first time in book form and presents the subject matter briefly and clearly.

The book is divided as follows: Chapter 1-Major Soil Divisions and their Geographic Qualifications (33 pages); Chapter 2—The Pedalfers (28 pages); Chapter 3—The Pedocals (16 pages); Chapter 4—Geographic Relationships (50 pages). A summary (4 pages), bibliography of 61 general references (5 pages), and subject index (8 pages) follow.

The author states in the preface: "The soil of the United States has long been recognized as one of its more important resources, yet geographic inquiries relating to the soils of the country as a whole have been almost wholly neglected. . . . . It is the object of this study to examine the largest of such (soil) groups which may be recognized in the United States—the major soil divisions; to set forth their fundamental functional characteristics and to determine some of their essential and more important geographic relationships." The soils of the United States are divided into two large groups—pedalfers and pedocals. The following groups of soils are considered under pedalfers: podsols, gray-brownerths, red- and yellowerths, ferruginous laterites, prairyerths. Under pedocals are: blackerths, chestnuterths, brownerths, grayerths.

Each of these groups of soils is considered in detail as regards location and extent, general characteristics, and factors active in its formation and utilization. The author has drawn particularly freely from the extensive work of Dr. C. F. Marbut of the U. S. Department of Agriculture; in fact, it is his thought which dominates the subject matter.

As with most new scientific studies, many new terms appear. Some may persist, others will probably be discarded, and still others may eventually be replaced by different terms before the subject matter is definitely established and accepted.

The treatise would have been greatly improved by the inclusion of more maps and diagrams. Representative diagrams of typical profiles of each of the soil divisions would have been particularly useful to the general reader.

The book should prove highly informative to all who are interested in soils, whether as geographers, chemists, or biologists. Although the information as a whole may not be new to students of soil classification, the book should prove helpful to them as a general summary of the available information concerning the large groups of the soils of the United States.

ROBERT L. STARKEY.